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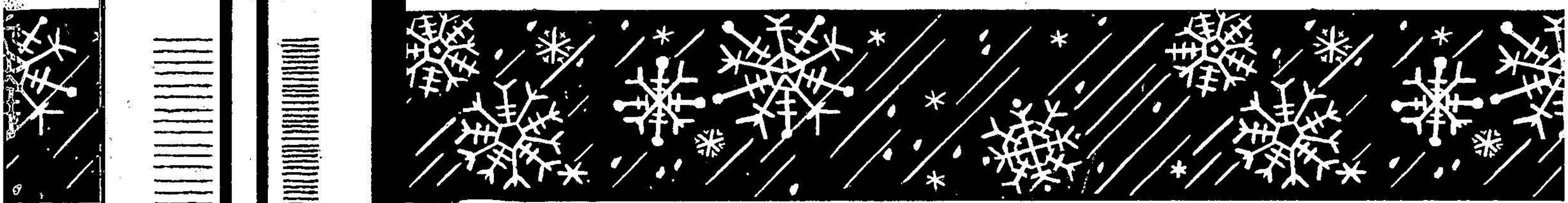

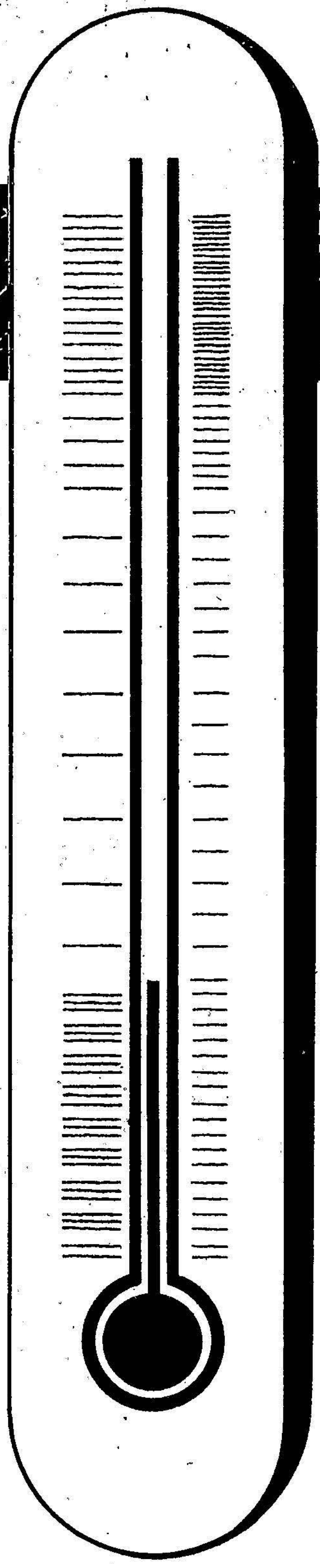

The occurrence of FREEZING TEMPERATURES in late spring and early fall

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THE OCCURRENCE OF FREEZING TEMPERATURES IN LATE SPRING AND EARLY FALL

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Every farmer, orchardist and truck gardener is well aware of the hazard to his crops posed by the threat of frost and freezing temperature. This hazard is present each year, and the main defense against it in this area consists of recognizing the extent to which there is a risk in planting and harvesting seasons. The average number of days between the last killing freeze in spring and first in fall customarily defines the length of the growing season; and it is surprising how variable this is, even over an area as small as the State of Ohio. This variability becomes even more evident when it is considered that some plants are severely damaged by temperatures only slightly below 32° while others are more resistant to cold. In general, plants are injured by freezing whenever irreversible protoplasmic changes take place within the plant tissues. The temperature at which damage occurs varies with the kind of plant as well as with its stage of development.

The appearance of frost in the form of ice crystals on the surfaces of leaves is popularly taken as visual indication of plant injury although in the case of freeze resistant varieties this is certainly not the case. On the other hand, low temperature damage can take place without any deposit of hoar frost whatever. This is the case when there is insufficient moisture in the air to condense at 32° F - the dewpoint

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of that air is below freezing. "Frosts" occurring under such conditions are often called "black frosts"; and it becomes obvious that the accumulation of feathery frost crystals is not a true indicator of the extent of plant injury. It is the low temperature which causes plant injury - not the frost deposit. The extent of injury sustained is determined, not only by the lowest temperature reached, but also by the duration of freezing temperatures, the rate of temperature change, the kind and condition of plants, and very likely by several other factors. This explains why the Weather Bureau some 10 years ago ceased to record the occurrences of frost, and started keeping a detailed record of the last 32°, 28°, 24°, 20°, and 16° temperatures in spring and the first such occurrences in fall.

FREEZING TEMPERATURE AND INJURY TO PLANTS

The severity of freeze sustained, as it relates to temperature levels may be roughly defined as follows (1)

Table 1

Severity	Temp. Limits	Type of Damage
Light	28-32°	Little or no damage to most plants. Heavy damage to tender plants and semi-hardy plants in low lands.
Moderate	24-28°	Some damage to most plants. Heavy damage to fruit blossoms, tender and semi-hardy plants, particularly in low spots.
Severe	Less than 24°	Heavy damage to most plants not in a dormant condition.

Examples of tender vegetables are garden beans, sweetcorn, melons and pumpkins; semi-hardy are beets, carrots, parsnips, lettuce, and spinach;

while turnips, peas, cabbage, onions and radishes are classed as hardy. Certain fruits have been classified by Gardner et al. (2) based upon observations by various workers as follows:

TEMPERATURE DANGER POINTS FOR CERTAIN FRUITS

Table 2

Fruit	STAGE OF PLANTS: Buds closed but showing color	In blossom	Setting fruit
Apple	25 - 27	28 - 29	28 - 30
Peach	20 - 29	25 - 30	27 - 30
Cherry	22 - 29	28 - 30	28 - 30
Plum	25 - 30	28 - 31	28 - 31
Grape	30	31	31

Strawberries are susceptible to damage by 32° temperatures, while heavy damage occurs at slightly lower readings when blossoming. After the berries have set, plants are more resistant to freezing.

In spring 30° will generally kill exposed, above ground parts of corn and soybeans, while in the fall 30° causes partial defoliation, and 28° causes both killing and defoliation of soybeans, depending upon the density of foliage and the duration of such temperatures.

As one example of the freeze risk in fall, the following estimates of low temperature danger to germination potentialities of seed corn may be quoted. In an extensive study of this problem, Kiesselbach and Radcliff (3) found that the moisture content of kernels is the most important factor in freeze injury. The following table represents a condensation of part of their findings.

PERCENT OF KERNELS GERMINATING AFTER 24-HOUR
EXPOSURE TO INDICATED TEMPERATURE

Table 3

Percent Moisture in Grain	TEMPERATURE RANGE (DEGREES F.) 32 to 28	24 to 20	16 to 12	8 to 4	0 to -5
35-40	71	13	0	0	0
30-35	75	67	12	0	0
25-30	85	77	34	7	0
20-25	100	96	88	47	0
15-20	---	100	100	98	63
10-15	---	---	---	100	97

Corn protected by husks were found able to withstand exposure to 26° temperatures for 12 hours even though moisture content was 45 to 50 percent. Similar results were obtained by Rossman (4,5) who stressed the fact that rate of fall is also an important factor in freeze injury.

Recognizing the wide variation of susceptibility to freeze damage, plus the fact that injury may result without any visual deposit of frost, all data presented in this bulletin are tied to the occurrence of specific temperatures. The term "freeze" is substituted for "frost" in most cases, recognizing that whenever frost occurs the surface temperature must be at least as low as 32°F.

Farmers and gardeners have many times noticed that frost crystals may form on the ground when thermometers in the instrument shelter or on the "back porch" read 36° or even higher. This shows conclusively, of course, that ground temperatures were colder than the air above - a common occurrence. Temperatures fall at night simply because the surface radiates its heat to outer space, and this loss of heat is most rapid on clear, calm nights when there is no blanket of clouds to hold it in. It is the surface - ground surface, buildings, vegetation, etc. - which radiates heat, and the air is cooled mainly by contact with that surface. Thus a low-level "temperature inversion" (coldest in lowest layers) is built up which, within a vertical distance of 5 feet (the standard thermometer height) may on occasions be as much as 10 degrees. Frost or freezing temperatures can occur on low-growing plants, therefore, when the air is 36, 38 or even 40 degrees. In fact, leaf surfaces themselves can reach the freezing point by radiation before frost forms on bare ground because of the heat stored in leaves is minute compared with that retained in the soil mass.

Because of the possibility of freeze damage to vegetation when air temperature is above freezing this report includes the probability occurrence of 36° as well as that of 32° and lower temperatures.

WEATHER CONDITIONS FAVORABLE FOR LATE SPRING AND EARLY FALL FREEZES

In practically all instances the late spring or early fall freeze results from a special set of circumstances which are easily recognized. First an unseasonably cold outbreak of polar air must arrive to "set the stage" by taking the regional temperature down into an unseasonably cold range. Then, if the sky is clear and the wind calm the usual night-time cooling can easily depress the temperature the remaining distance to freezing by daybreak. The drier the air and the clearer the atmosphere the greater the rate of fall. Because wind mixes the layers of air, dissipating the super-cooled surface air and bringing down warmer air from above, latest spring and earliest fall freezes almost always occur on calm nights. In some instances, however, the arrival of an unusually cold air mass may result in a damaging freeze even though the sky is cloudy and there is plenty of wind. Under such conditions the second night is likely to be colder than the first because by then the sky will usually have had time to clear, and the wind to die down.

INFLUENCE OF LOCATION AND TOPOGRAPHY

Although all temperatures used in this study were standard Weather Bureau minimum readings, they may not be and frequently are not the exact temperatures to which plants in the area are subjected. As mentioned above, 5 feet is the standard height for thermometer exposures. And, not all thermometers are identically located with relation to buildings, trees, slope of the land, etc. Nevertheless, the air close to the ground is a zone of disturbance, and by using a height of 5 feet, some of this extreme variability is compensated for. The data are therefore made valid for a larger surrounding area, although appreciable differences may occur because of local influences, mostly topographical.

When attempting to judge the temperature in a given spot there are several basic concepts which must be considered. The following are most important:

1. The temperature close to the ground and near plant surfaces on frosty nights is almost always colder than is the air above. It is therefore possible for plants to freeze even though the measured air temperature is well above 32°.

2. Low spots are usually cold spots, no matter how small or large they may be. Cold air, being heavier than warm, will collect in pools just as water does, often making "frost pockets" of small size. This same effect may be caused by obstructions on hillsides, such as a row of trees, which tends to dam up the downward flow of cold air at night. In such situations it is always coldest on the uphill side of the obstruction.

3. The same principle makes temperatures lower in valleys than on adjacent hillsides on clear nights with little wind. This effect accounts for many of the late spring and early fall freezes in hilly parts of southern Ohio. Reporting stations are generally situated in valleys.

4. All other factors being equal, temperatures in northern parts of the state are colder than in southern sections. While "other factors" tend to obscure this latitude effect in Ohio, Corton (6) found that in Iowa the mean date of last spring freeze is 5 days later, and the mean date of first fall freeze 4 days earlier per degree increase in latitude. (One degree of latitude is about 70 miles).

5. Differences in the general altitude of terrain exerts a smaller, but significant influence upon minimum temperatures. Small valleys at high elevations are colder than similar valleys several hundred feet lower. This accounts for the later spring and earlier fall freezes in northeastern hills areas south of Youngstown.

6. The presence of sizeable bodies of water exerts a large

ameliorating influence upon temperature. The presence of Lake Erie on Ohio's northern border, for example, holds off the occurrence of freezes in fall along the lake shore, and advances the freeze-free date in spring by as much as 2 weeks.

7. Of lesser general importance are such factors as the color and heat conductivity of soils, and the proximity to trees, buildings and other obstructions. Due to its dark color and low heat conductivity, the risk of frost in peat bogs is materially increased. Plants protected by trees or tall shrubs, on the other hand, are less likely to freeze because the higher plants tend to protect the lower growth by reducing radiation losses.

A combination of these factors plus the presence of large buildings, pavement, and atmospheric pollutants in larger cities results in notable differences between downtown, residential and open country locations. Differences in minimum temperature between downtown and open country sites sometimes amount to 10 degrees or more, while residential areas occupy an intermediate position.

STATIONS AND TEMPERATURE DATA USED

The geographical distribution of weather stations used in this study is shown in Figure 1; while details as to station name, county, coordinates and elevation are given in Table 4. While only those stations with a long observational record were used, the actual selection was made by the Weather Bureau's Office of Climatology on statistical grounds.

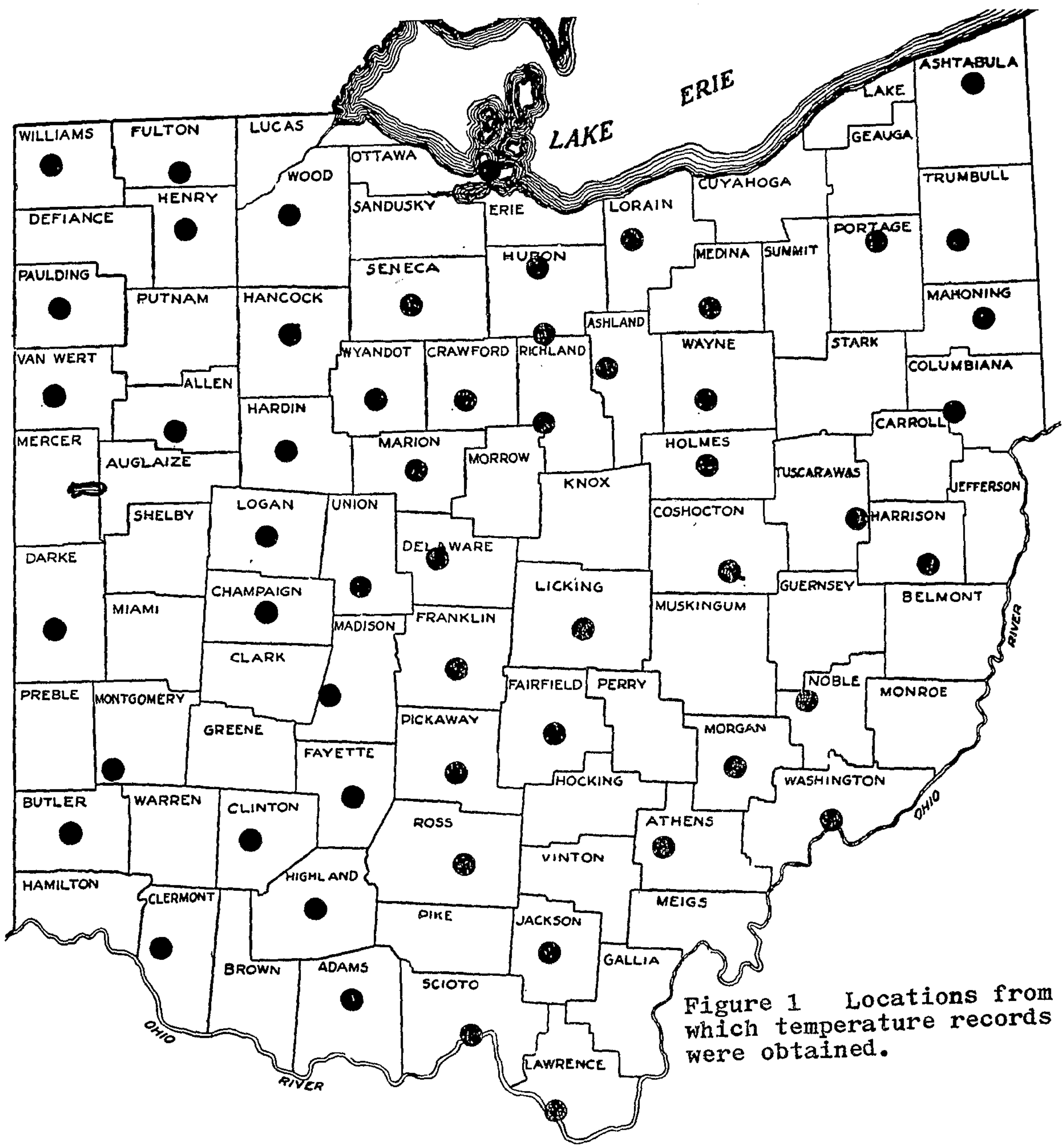

Figure 1 Locations from which temperature records were obtained.

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Station Locator

Table 4

	County	Latitude	Longitude	Elevation (feet)
Ashland	Ashland	40° - 53'	82° - 22'	1190
Athens	Athens	39° - 23'	82° - 11'	685
Batavia	Clermont	39° - 07'	84° - 10'	850
Bellefontaine	Logan	40° - 21'	83° - 46'	1185
Bowling Green	Wood	41° - 23'	83° - 38'	675
Bucyrus	Crawford	40° - 48'	82° - 58'	1000
Cadiz	Harrison	40° - 16'	81° - 00'	1270
Caldwell	Noble	39° - 49'	81° - 36'	980
Canfield	Mahoning	41° - 00'	80° - 45'	1160
Catawba Island	Ottawa	41° - 33'	82° - 51'	600
Chillicothe	Ross	39° - 20'	82° - 58'	638
Chippewa Lake	Medina	41° - 05'	81° - 54'	1040
Circleville	Pickaway	39° - 36'	82° - 57'	690
Cols Valley Crossing	Franklin	39° - 56'	82° - 57'	760
Coshocton	Coshocton	40° - 15'	81° - 52'	750
Delaware	Delaware	40° - 18'	83° - 04'	840
Dennison	Tuscarawas	40° - 24'	81° - 21'	845
Findlay	Hancock	41° - 03'	83° - 40'	768
Germantown	Montgomery	39° - 38'	84° - 24'	740
Greenville	Darke	40° - 06'	84° - 38'	1035
Hamilton	Butler	39° - 22'	84° - 33'	590
Hillsboro	Highland	39° - 12'	83° - 37'	1100
Hiram	Portage	41° - 19'	81° - 09'	1260
Ironton	Lawrence	38° - 32'	82° - 10'	555
Jackson	Jackson	39° - 04'	82° - 39'	700
Jefferson	Ashtabula	41° - 44'	80° - 46'	965
Kenton	Hardin	40° - 39'	83° - 39'	1015
Lancaster	Fairfield	39° - 44'	82° - 37'	920
Lima	Allen	40° - 43'	84° - 07'	860
London	Madison	39° - 54'	83° - 31'	1120
Mansfield	Richland	40° - 45'	82° - 38'	1290
Marietta	Washington	39° - 25'	81° - 27'	830
Marion	Marion	40° - 36'	83° - 10'	920
Marysville	Union	40° - 14'	83° - 22'	1000
McConnellsville	Morgan	39° - 39'	81° - 51'	675
Millersburg	Holmes	40° - 34'	81° - 56'	950
Millport	Columbiana	40° - 43'	80° - 54'	1145
Montpelier	Williams	41° - 35'	84° - 36'	860
Napoleon	Henry	41° - 23'	84° - 07'	675
Newark	Licking	40° - 05'	82° - 25'	835
Norwalk	Huron	41° - 15'	82° - 37'	720

Station Locator

Table 4

	County	Latitude	Longitude	Elevation (feet)
Oberlin	Lorain	41° - 17'	82° - 13'	817
Paulding	Paulding	41° - 08'	84° - 35'	720
Peebles	Adams	38° - 56'	83° - 25'	825
Plymouth	Richland	41° - 00'	82° - 40'	1013
Portsmouth	Scioto	38° - 43'	82° - 59'	530
Tiffin	Seneca	41° - 07'	83° - 10'	760
Upper Sandusky	Wyandot	40° - 50'	83° - 17'	854
Urbana	Champaign	40° - 08'	83° - 45'	1055
Van Wert	Van Wert	40° - 52'	84° - 35'	795
Warren	Trumbull	41° - 15'	80° - 51'	900
Washington C. H.	Fayette	39° - 32'	83° - 25'	960
Wauseon	Fulton	41° - 33'	84° - 08'	740
Wilmington	Clinton	39° - 27'	83° - 50'	1026
Wooster	Wayne	40° - 47'	81° - 56'	1010

Table 5. Percentage Chance of 32° Freeze Occurring On or After Given Dates in Spring; and On or Before Given Dates in Fall.

Division and Station	SPRING						AUTUMN					
	90%	75%	50%	25%	10%	2%	2%	10%	25%	50%	75%	90%
NORTHWEST												
Bowling Green	Apr. 20	Apr. 28	May 6	May 15	May 23	June 2	Sep. 15	Sep. 23	Sep. 30	Oct. 8	Oct. 15	Oct. 23
Findlay	Apr. 16	Apr. 25	May 3	May 12	May 20	May 30	Sep. 16	Sep. 26	Oct. 3	Oct. 11	Oct. 19	Oct. 26
Lima	Apr. 16	Apr. 24	May 3	May 12	May 19	May 29	Sep. 16	Sep. 25	Oct. 3	Oct. 11	Oct. 19	Oct. 26
Montpelier	Apr. 17	Apr. 26	May 4	May 13	May 21	May 31	Sep. 17	Sep. 26	Oct. 3	Oct. 11	Oct. 19	Oct. 26
Napoleon	Apr. 16	Apr. 24	May 3	May 12	May 20	May 29	Sep. 18	Sep. 27	Oct. 4	Oct. 12	Oct. 20	Oct. 27
Paulding	Apr. 20	Apr. 28	May 7	May 16	May 24	June 3	Sep. 14	Sep. 22	Sep. 30	Oct. 7	Oct. 15	Oct. 22
Van Wert	Apr. 19	Apr. 27	May 6	May 15	May 22	June 2	Sep. 15	Sep. 24	Oct. 1	Oct. 9	Oct. 17	Oct. 24
Wauseon	Apr. 20	Apr. 27	May 6	May 15	May 23	June 1	Sep. 18	Sep. 28	Oct. 5	Oct. 13	Oct. 21	Oct. 28
NORTH CENTRAL												
Bucyrus	Apr. 18	Apr. 25	May 3	May 11	May 18	May 26	Sep. 16	Sep. 25	Oct. 2	Oct. 9	Oct. 17	Oct. 24
Catawba Island	Apr. 3	Apr. 10	Apr. 18	Apr. 26	May 3	May 12	Oct. 7	Oct. 16	Oct. 23	Oct. 30	Nov. 7	Nov. 14
Norwalk	Apr. 25	May 2	May 10	May 18	May 25	June 3	Sep. 17	Sep. 25	Oct. 2	Oct. 10	Oct. 17	Oct. 24
Oberlin	Apr. 22	Apr. 29	May 7	May 15	May 22	May 31	Sep. 20	Sep. 28	Oct. 5	Oct. 12	Oct. 20	Oct. 26
Plymouth	Apr. 22	Apr. 29	May 7	May 15	May 22	May 31	Sep. 15	Sep. 24	Oct. 1	Oct. 8	Oct. 16	Oct. 23
Tiffin	Apr. 17	Apr. 25	May 2	May 10	May 18	May 26	Sep. 19	Sep. 28	Oct. 5	Oct. 12	Oct. 20	Oct. 27
Upper Sandusky	Apr. 19	Apr. 26	May 4	May 12	May 20	May 28	Sep. 15	Sep. 24	Oct. 1	Oct. 8	Oct. 16	Oct. 23
NORTHEAST												
Chippewa Lake	Apr. 27	May 5	May 14	May 22	May 30	June 8	Sep. 14	Sep. 23	Sep. 29	Oct. 7	Oct. 15	Oct. 21
Jefferson	Apr. 17	Apr. 25	May 3	May 12	May 20	May 29	Sep. 23	Oct. 2	Oct. 8	Oct. 16	Oct. 24	Oct. 31
Hiram	Apr. 20	Apr. 28	May 6	May 15	May 22	June 1	Sep. 20	Sep. 29	Oct. 6	Oct. 14	Oct. 22	Oct. 29
Warren	Apr. 25	May 3	May 12	May 20	May 28	June 7	Sep. 13	Sep. 22	Sep. 29	Oct. 7	Oct. 15	Oct. 22
WEST CENTRAL												
Bellefontaine	Apr. 18	Apr. 26	May 4	May 13	May 21	May 30	Sep. 15	Sep. 25	Oct. 2	Oct. 10	Oct. 19	Oct. 26
Greenville	Apr. 13	Apr. 21	Apr. 30	May 9	May 16	May 26	Sep. 19	Sep. 28	Oct. 6	Oct. 14	Oct. 23	Oct. 30
Kenton	Apr. 20	Apr. 28	May 7	May 16	May 23	June 2	Sep. 13	Sep. 22	Sep. 30	Oct. 8	Oct. 17	Oct. 24
Urbana	Apr. 15	Apr. 23	May 2	May 11	May 19	May 28	Sep. 18	Sep. 26	Oct. 3	Oct. 11	Oct. 18	Oct. 25
CENTRAL												
Chillicothe	Apr. 9	Apr. 17	Apr. 25	May 3	May 11	May 20	Sep. 21	Sep. 30	Oct. 7	Oct. 15	Oct. 23	Oct. 30
Circleville	Apr. 12	Apr. 20	Apr. 28	May 6	May 13	May 23	Sep. 17	Sep. 27	Oct. 4	Oct. 12	Oct. 20	Oct. 28
Columbus	Apr. 16	Apr. 24	May 2	May 10	May 18	May 27	Sep. 18	Sep. 27	Oct. 4	Oct. 10	Oct. 20	Oct. 27
Delaware	Apr. 16	Apr. 23	May 1	May 9	May 17	May 26	Sep. 15	Sep. 25	Oct. 2	Oct. 10	Oct. 15	Oct. 25
Lancaster	Apr. 21	Apr. 29	May 7	May 16	May 23	June 1	Sep. 11	Sep. 20	Sep. 27	Oct. 5	Oct. 13	Oct. 20
London	Apr. 16	Apr. 24	May 2	May 10	May 18	May 27	Sep. 19	Sep. 29	Oct. 6	Oct. 14	Oct. 22	Oct. 31
Marion	Apr. 15	Apr. 23	May 1	May 9	May 17	May 26	Sep. 16	Sep. 25	Oct. 2	Oct. 10	Oct. 18	Oct. 26
Marysville	Apr. 19	Apr. 27	May 5	May 14	May 21	May 31	Sep. 16	Sep. 25	Oct. 2	Oct. 10	Oct. 18	Oct. 26
Newark	Apr. 20	Apr. 28	May 6	May 14	May 21	May 31	Sep. 7	Sep. 16	Sep. 23	Oct. 1	Oct. 9	Oct. 16
Washington CH	Apr. 12	Apr. 19	Apr. 28	May 6	May 13	May 23	Sep. 17	Sep. 27	Oct. 4	Oct. 12	Oct. 20	Oct. 27

Table 5. (continued)

Division and Station	SPRING 90%	75%	50%	25%	10%	2%	AUTUMN 2%	10%	25%	50%	75%	90%
CENTRAL HILLS												
Ashland	Apr. 21	Apr. 29	May 7	May 16	May 23	June 2	Sep. 17	Sep. 26	Oct. 3	Oct. 11	Oct. 19	Oct. 26
Coshocton	Apr. 17	Apr. 25	May 4	May 12	May 20	May 29	Sep. 17	Sep. 26	Oct. 3	Oct. 11	Oct. 19	Oct. 26
Mansfield	Apr. 23	May 1	May 9	May 18	May 25	June 4	Sep. 12	Sep. 21	Sep. 28	Oct. 6	Oct. 14	Oct. 21
Millersburg	Apr. 25	May 3	May 12	May 21	May 29	June 8	Sep. 10	Sep. 19	Sep. 26	Oct. 4	Oct. 12	Oct. 19
Wooster	Apr. 25	May 3	May 11	May 20	May 27	June 6	Sep. 12	Sep. 20	Sep. 27	Oct. 5	Oct. 13	Oct. 20
NORTHEAST HILLS												
Cadiz	Apr. 15	Apr. 23	May 1	May 9	May 17	May 26	Sep. 20	Sep. 28	Oct. 6	Oct. 13	Oct. 21	Oct. 28
Canfield	Apr. 29	May 7	May 15	May 24	May 31	June 6	Sep. 10	Sep. 19	Sep. 26	Oct. 4	Oct. 12	Oct. 20
Dennison	Apr. 26	May 3	May 12	May 20	May 28	June 1	Sep. 8	Sep. 18	Sep. 25	Oct. 3	Oct. 12	Oct. 19
Millport	May 2	May 10	May 18	May 27	June 4	June 13	Sep. 6	Sep. 15	Sep. 22	Sep. 30	Oct. 8	Oct. 15
SOUTHWEST												
Batavia	Apr. 12	Apr. 20	Apr. 28	May 7	May 15	May 26	Sep. 18	Sep. 27	Oct. 5	Oct. 13	Oct. 22	Oct. 29
Germantown	Apr. 10	Apr. 18	Apr. 27	May 6	May 14	May 24	Sep. 17	Sep. 25	Oct. 5	Oct. 13	Oct. 21	Oct. 29
Hamilton	Apr. 13	Apr. 21	Apr. 30	May 5	May 16	May 26	Sep. 19	Sep. 28	Oct. 6	Oct. 14	Oct. 23	Oct. 30
Hillsboro	Apr. 12	Apr. 20	Apr. 29	May 7	May 15	May 25	Sep. 19	Sep. 28	Oct. 6	Oct. 14	Oct. 23	Oct. 30
Wilmington	Apr. 15	Apr. 23	May 2	May 10	May 18	May 29	Sep. 14	Sep. 23	Oct. 1	Oct. 9	Oct. 18	Oct. 25
SOUTH CENTRAL												
Ironton	Apr. 6	Apr. 14	Apr. 23	May 2	May 9	May 20	Sep. 22	Oct. 1	Oct. 8	Oct. 16	Oct. 25	Nov. 1
Jackson	Apr. 13	Apr. 22	Apr. 30	May 9	May 12	May 27	Sep. 15	Sep. 24	Oct. 2	Oct. 10	Oct. 18	Oct. 26
Peebles	Apr. 17	Apr. 26	May 4	May 13	May 21	May 31	Sep. 13	Sep. 22	Sep. 29	Oct. 7	Oct. 15	Oct. 23
SOUTHEAST												
Caldwell	Apr. 13	Apr. 21	Apr. 29	May 8	May 16	May 25	Sep. 22	Sep. 30	Oct. 7	Oct. 15	Oct. 22	Oct. 29
Marietta	Apr. 10	Apr. 18	Apr. 27	May 5	May 14	May 24	Sep. 22	Sep. 30	Oct. 7	Oct. 14	Oct. 22	Oct. 29
McConnelsville	Apr. 16	Apr. 25	May 3	May 12	May 20	May 30	Sep. 20	Sep. 29	Oct. 10	Oct. 13	Oct. 21	Oct. 27
Athens	Apr. 11	Apr. 19	Apr. 28	May 7	May 14	May 24	Sep. 18	Sep. 26	Oct. 3	Oct. 10	Oct. 18	Oct. 25

Computations of average dates and standard deviations were made by machine methods in the National Weather Records Center in Asheville, N. C. Except for some relative sparseness in two or three areas, the number is sufficient and distribution adequate to give a good representation of variations over the state. Included in the original list were several large cities, among them Columbus, Cincinnati, Cleveland, Toledo, Sandusky, and Akron. These records were intentionally omitted from this study because of their large urban influence. About half of the stations used, are in rural settings, while the remainder are in residential sections of smaller towns. Except for the ever-present local influences, therefore, all data are considered representative of their respective areas. No attempt has been made to allow for known local influences beyond a smoothing of date lines on probability maps.

Footnote 1. Original data have been processed for 20° and 16° also, but probability dates for these lower temperatures have not been included. They may be obtained, however, by applying the following adjustment factors. In spring the last occurrence of 20° and 16° for all probability levels may be obtained by subtracting 42 days and 53 days, respectively from corresponding dates for 32°. In fall the adjustment factors are 39 days and 50 days, respectively.

DATA PRESENTED

Information contained in this report consists of the probability occurrence of significant threshold temperatures. 36°, 32°, 28°, and 24° are considered of greatest importance for reasons already discussed.[1] Table 5 shows the percentage chance of the last 32° freeze occurring after the spring dates quoted; also the percentage chance in fall that the first 32° freeze will already have occurred by the dates shown. These data are given for all stations listed in Table 4 whose geographical location is shown in figure 1. These same data have been plotted on maps to show their distribution over the state, and to permit a selection of dates to be made for other locations. See figures 6-9, incl., for spring dates and 22-25 for fall dates. Similar maps are presented to show the percentage chance of occurrence for 36°, 28° and 24°, these representing freezes of less or greater severity.

These maps were obtained by plotting corresponding dates for all 55 stations listed in Table 4. Thom and Shaw (8) have shown that freeze dates for a given threshold temperature are normally distributed; and that differences in standard deviation between stations over a sizeable area have no real significance. Consequently, an average standard deviation for the entire state was used for all stations and all threshold temperatures on the assumption that differences were due mainly to local topographic influences. Dates used were then obtained by using normal probability paper - plotting the mean date at 50%, and the mean plus (and minus) twice the standard deviation at 2.275% and 97.725% respectively. Dates were then taken from this straight-line curve.

PERCENTAGE CHANCE OF A FREEZE

The length of growing season has for many years been defined as the number of days between the average date of the last "killing frost" in the spring and the first in the fall. Naturally, frosts seldom fall exactly on the average date, but range widely from year to year. Now that specific temperatures (36°, 32°, etc.) are being used in place of the ill-defined "killing frost" the data respond more readily to statistical treatment. The risk of getting freezes of indicated severity can now be expressed in terms of percentage probabilities for any date. On the average date, for example, there is a 50-50 chance of the first freeze in fall occurring before or after that date. Over a long period of years, then half of the first occurrences will fall before, and half after that date. In terms of probabilities the average date is expressed as a 50% chance. In many operations, however, it may be of value to know what risk would have to be accepted at times earlier or later than the average date.

A commercial gardener, for example, will not want to wait until all danger of a freeze is past before starting spring operations. In most cases an early start is desirable to insure an early market; and therefore tender plants have to be set out or seedings made with the realization that there is still some danger of a later freeze. Farmers and gardeners are accustomed to taking such calculated risks - it is part of the business - but they do not always know just how much risk they are actually taking. It is the purpose of this study, then, to evaluate these freeze risks, and furnish dates for all parts of Ohio on which there is a specified risk of various "threshold temperatures", such as 36, 32, 28, and 24. An example will serve to illustrate how this information may be used.

Suppose a farmer living in southwestern Pickaway County decided to plant sweet-corn about May 1. Sweet-corn is a tender plant and it would be necessary to figure the chances of a 32° freeze after the date of emergence, say May 5. Referring to the set of spring maps for 32 degrees, then, it can be seen that the date line for May 5 on figure 8 runs through southwestern Pickaway County. This is the map for 25% risk, which means that there is 1 chance in 4 that a temperature as low as 32° will occur after May 5. For the sake of getting an earlier start, it might be feasible to take an even greater risk; and the approximate planting dates for other levels of risk can be obtained from other maps in the spring series (Figures 2-17).

This same kind of information can be obtained for temperatures other than 32°; also for fall freezes as well as those in spring. It should be clearly understood, however, that these dates refer to the <u>last</u> freeze in spring, and the <u>first</u> freeze in fall. Also it is important to recognize that the risk of freezes is always greater in valley bottoms than elsewhere in hilly terrain. Dates quoted on all maps are intended to represent an average condition, although in hilly sections, they will come closer to representing actual risk in valley bottoms. In general, the proper procedure is first to determine the level of temperature which would constitute a real hazard to the plants involved, and then to decide just how much risk you are willing to assume. By referring to the one map made for that temperature and that risk, the proper date can be obtained by simply locating yourself on the map. The description supplied with each map is self-explanatory. For semi-hardy plants like lettuce and beets, for example, you might refer to probability maps for 28°; while for hardy plants like spinach and peas, maps for 24° might be more appropriate. In the case of tenderest plants it might be wise to consult maps for both 36° and 32°.

PATTERN OF FREEZE DATES IN SPRING AND FALL

Except for minor differences, the general pattern of freeze date distribution is the same for all temperatures, and all levels of freeze risk for both spring and fall. This simply means that the colder portions of the state have later freezes in spring and earlier freezes in fall than do the warmer sections. It is surprising to note, however, how much difference there is between the various parts of the state. The effect of latitude is clearly evident, as might be expected, but this is almost completely overshadowed by the effect of topography and proximity to Lake Erie. Areas free from the danger of freezing temperatures on the earliest dates in spring are those in the lower Scioto Valley, along the Ohio River, and in a narrow strip along the lake shore. The coldest part of the state is in the northeastern hills south of Youngstown; and this general area of coldness spreads southward for a surprising distance over central and southern hills. This is due in large part to the fact that observing stations are almost always located in the valleys. The Scioto Valley, by contrast, is milder than at equivalent latitudes east or west-even as far north as Marion County.

It must be recognized that freeze dates shown on the maps are somewhat generalized because it would be impossible to show all the minor variations due to local differences in topography. In most cases, however, the departure from dates shown should seldom exceed five days.

GROWING SEASON

The term "growing season", or freeze-free season has been widely used to designate that part of the year between the average date of the last freeze in spring and the first in the fall. However, the effective growing season available for any crop differs from this figure by an amount which depends upon the time the crop is planted, or commences growth in the spring, and the time it matures or is killed by freezing weather in the fall. May 2 is the average last spring date for 32° for Ohio, and Oct. 11 is the state average for first 32°. This makes the state's average freeze-free period or "growing season" 162 days. Among all the stations used in this study Tiffin comes closest to meeting both average dates. (May 2 to Oct. 12)

Since crops are not ordinarily sown on the first day of the theoretical "growing season", the actual growing season for any crop may be quite different from the theoretical one. This makes a difference also in the total amount of risk assumed by the grower, as pointed out by Shaw et al. (7). For example, if May 15 were the usual planting date for corn in the Tiffin area, this would make the corn growing season 149 days (May 15 to Oct. 12) instead of the full 162 days quoted above. Then, if one wished to know the total freeze risk he would run by planting on May 15, he would have to combine the risk of a later spring freeze with that of a fall freeze coming before the average date. It turns out that in this case the risk of a 32° freeze after May 15 is 14 percent, while that of a similar freeze occurring before Oct. 12 is obviously 50 percent.

$$\frac{14}{100} \times \frac{50}{100} = 7\%$$

This, of course, is more favorable than would be the case if planting were done on the first day of the theoretical growing season -

$$\frac{50}{100} \times \frac{50}{100} = 25\%.$$

The same situation exists for other annual crops. Nevertheless, as a quotable figure, the "growing season" serves as a convenient basis for comparing climates over the country. The distribution of growing season lengths over the state of Ohio is shown in figure 34.

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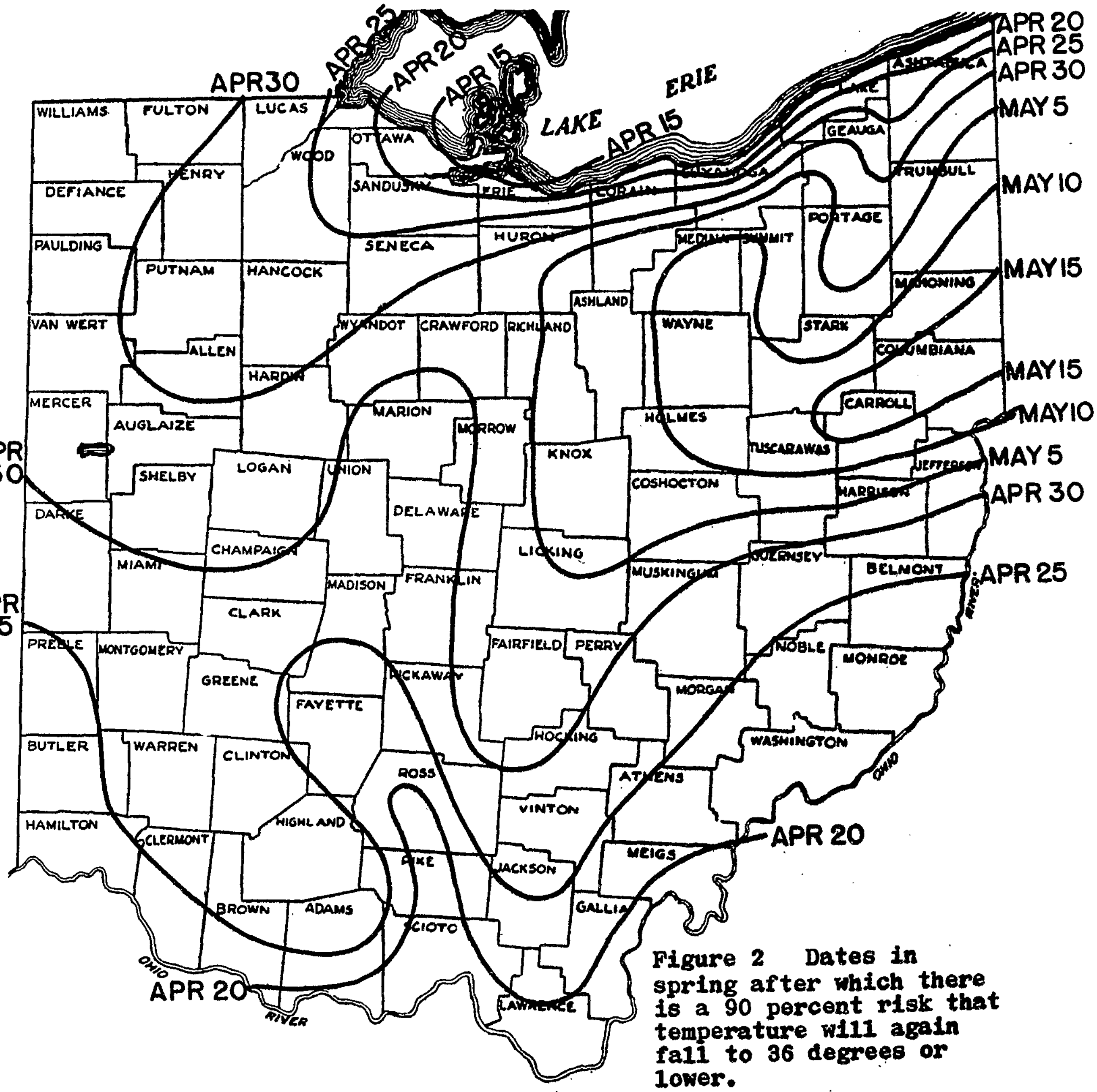

Figure 2 Dates in spring after which there is a 90 percent risk that temperature will again fall to 36 degrees or lower.

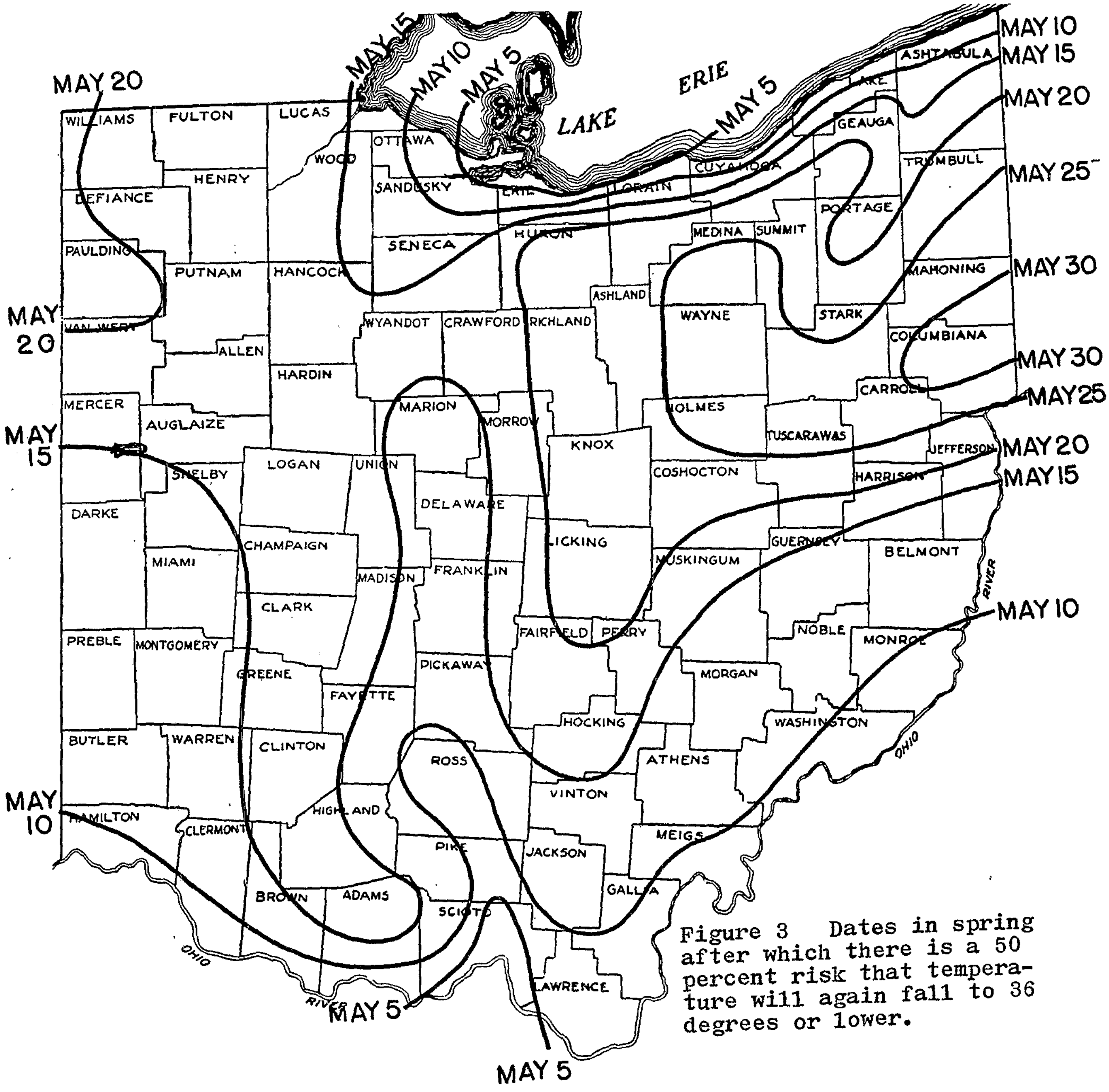

Figure 3 Dates in spring after which there is a 50 percent risk that temperature will again fall to 36 degrees or lower.

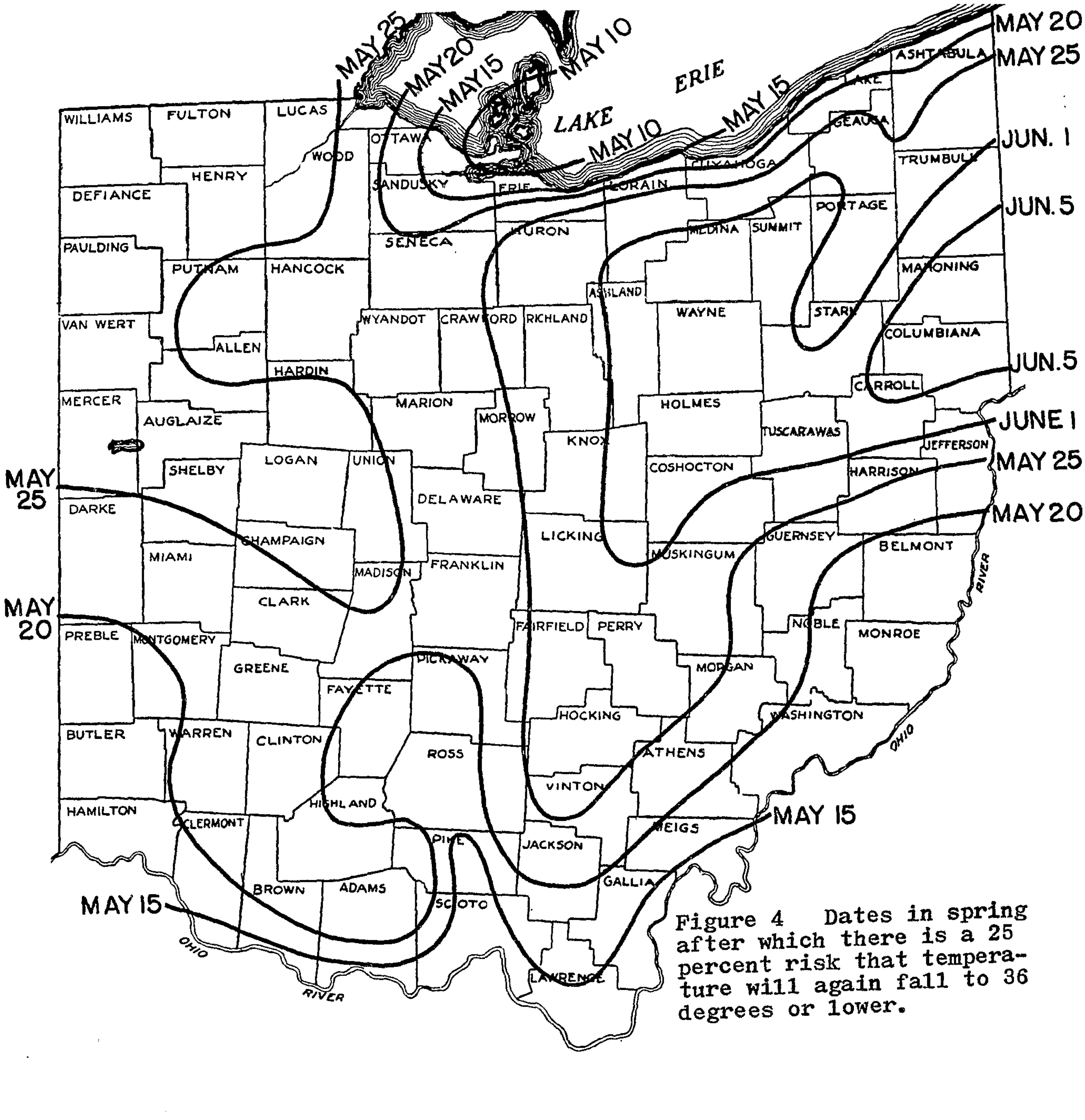

Figure 4 Dates in spring after which there is a 25 percent risk that temperature will again fall to 36 degrees or lower.

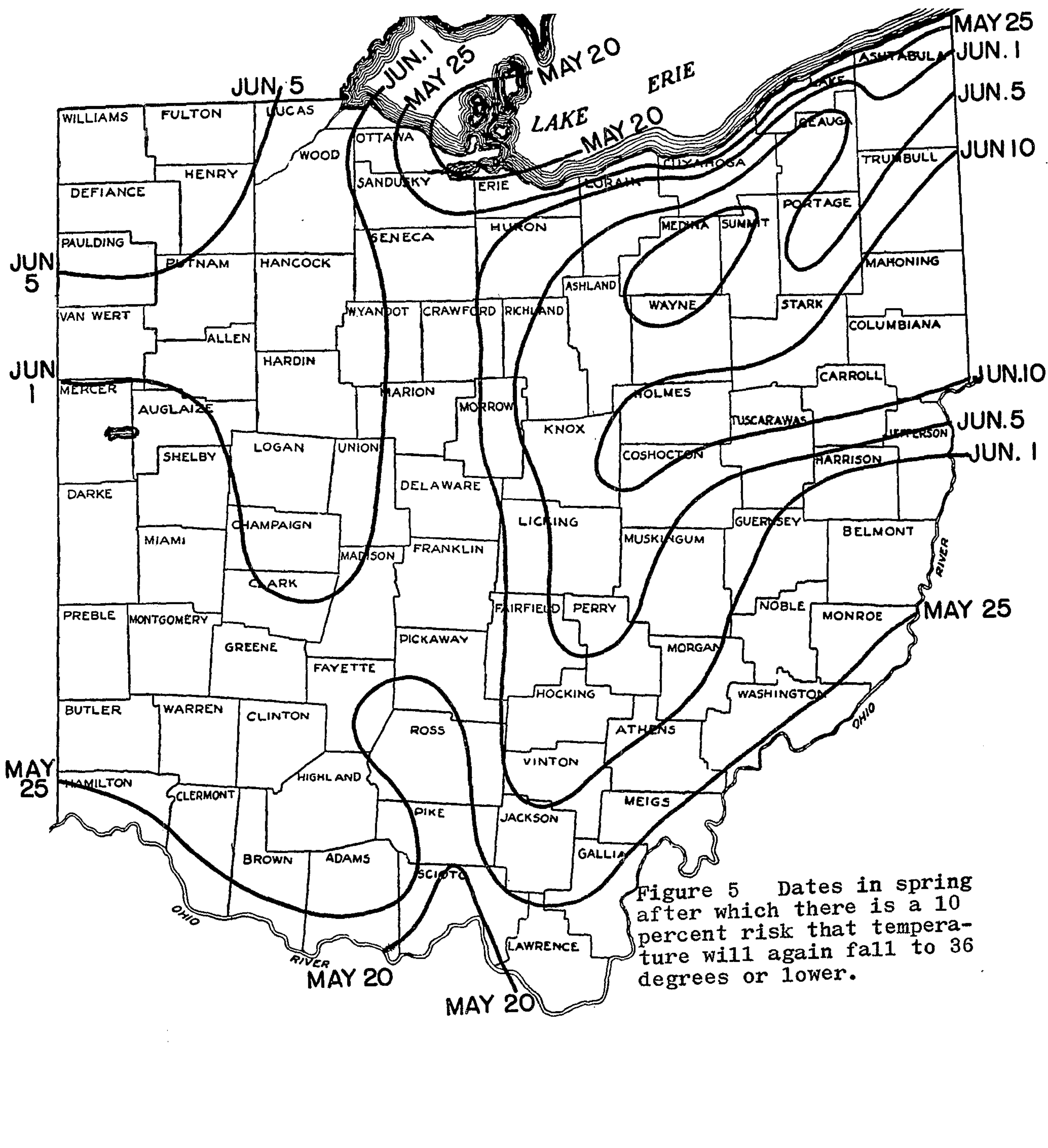

Figure 5 Dates in spring after which there is a 10 percent risk that temperature will again fall to 36 degrees or lower.

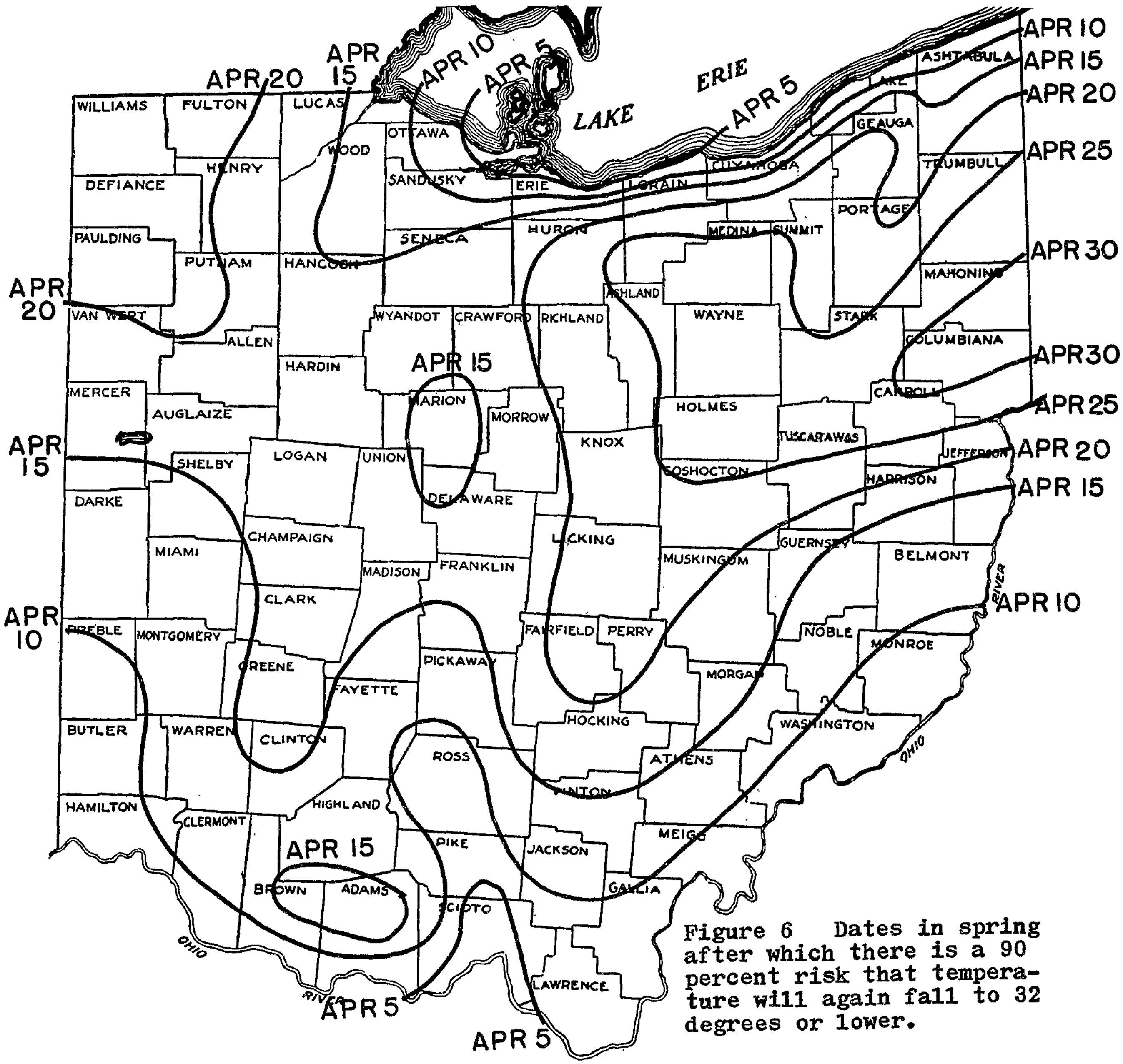

Figure 6 Dates in spring after which there is a 90 percent risk that temperature will again fall to 32 degrees or lower.

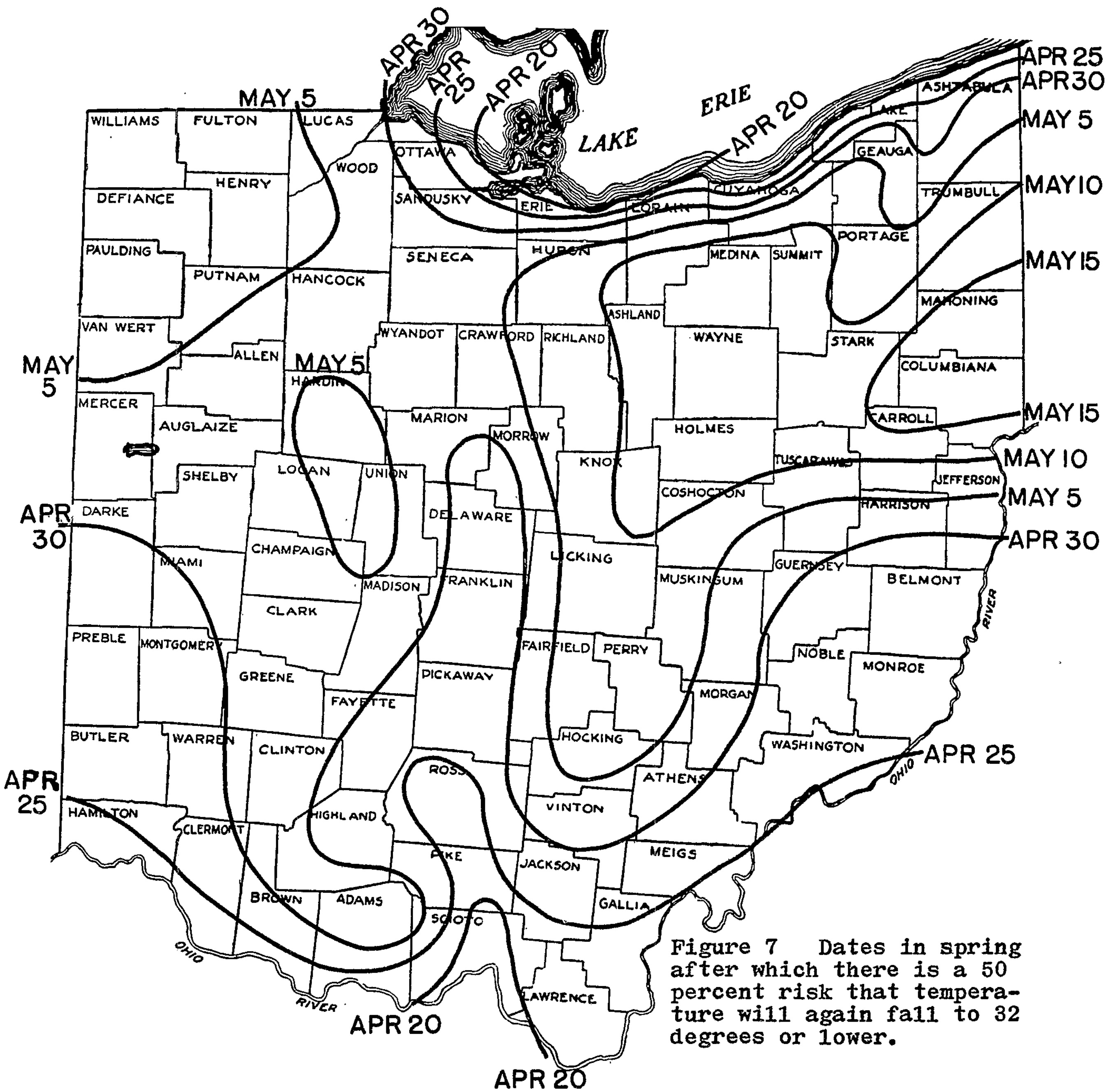

Figure 7 Dates in spring after which there is a 50 percent risk that temperature will again fall to 32 degrees or lower.

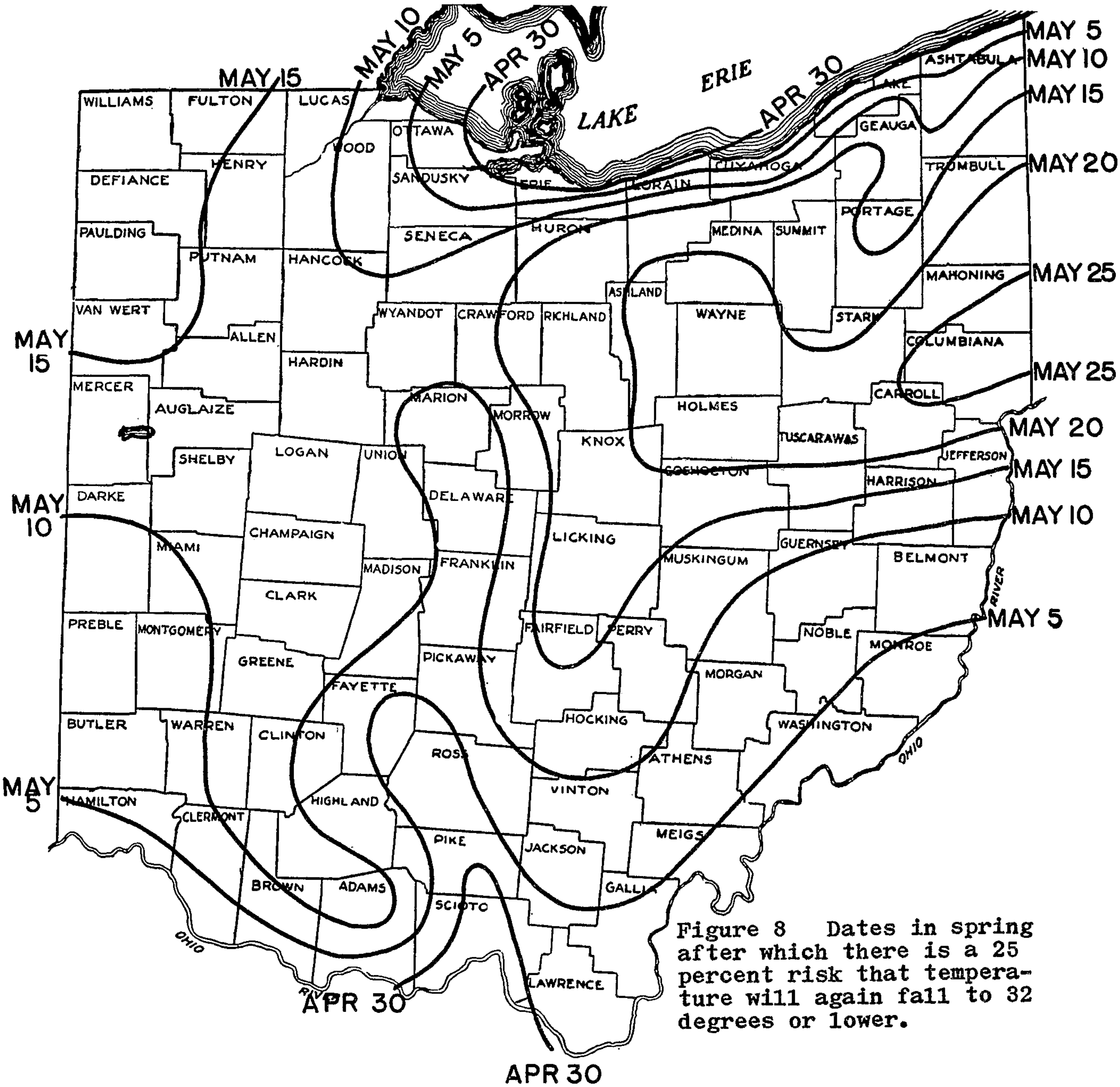

Figure 8 Dates in spring after which there is a 25 percent risk that temperature will again fall to 32 degrees or lower.

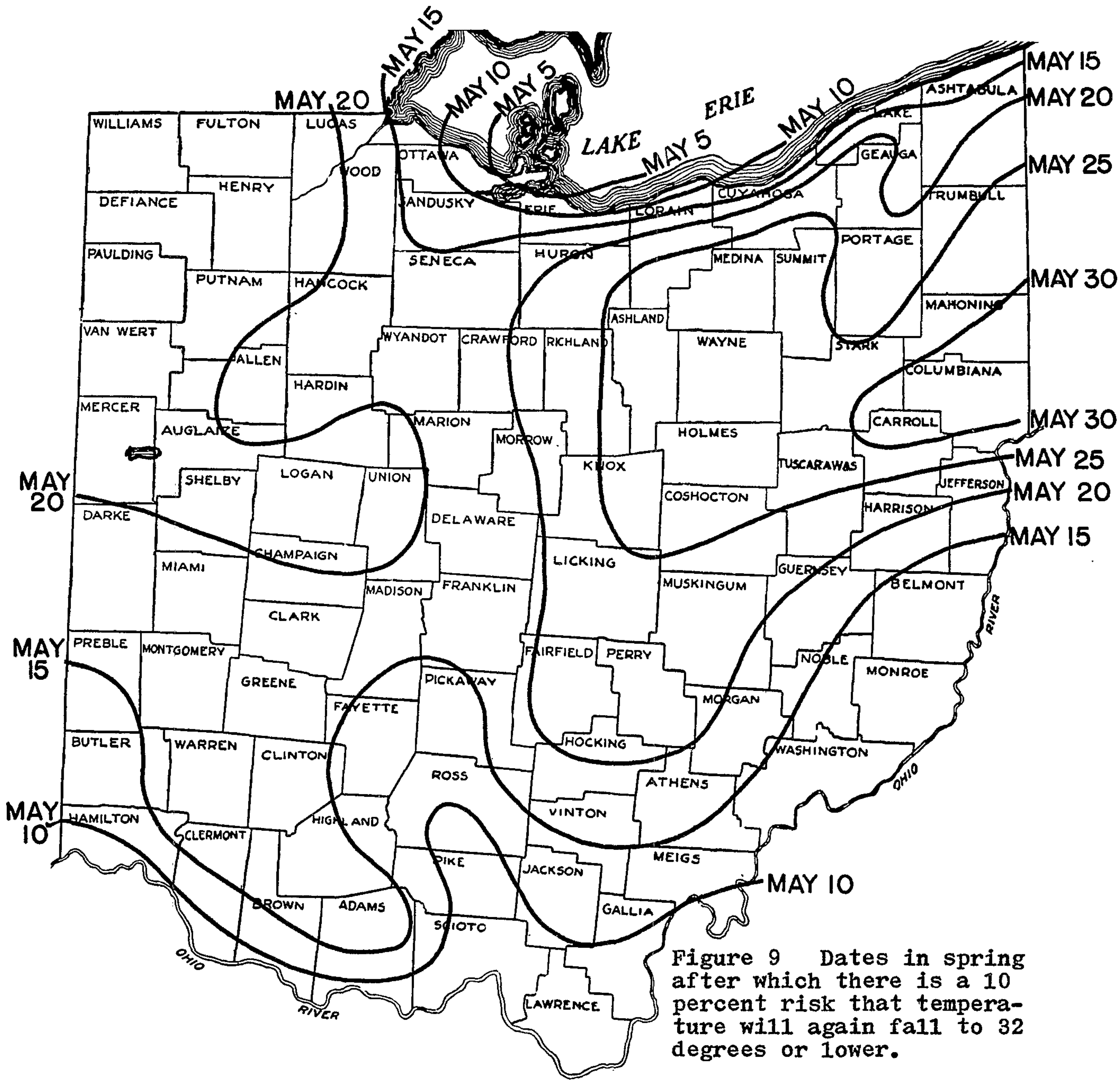

Figure 9 Dates in spring after which there is a 10 percent risk that temperature will again fall to 32 degrees or lower.

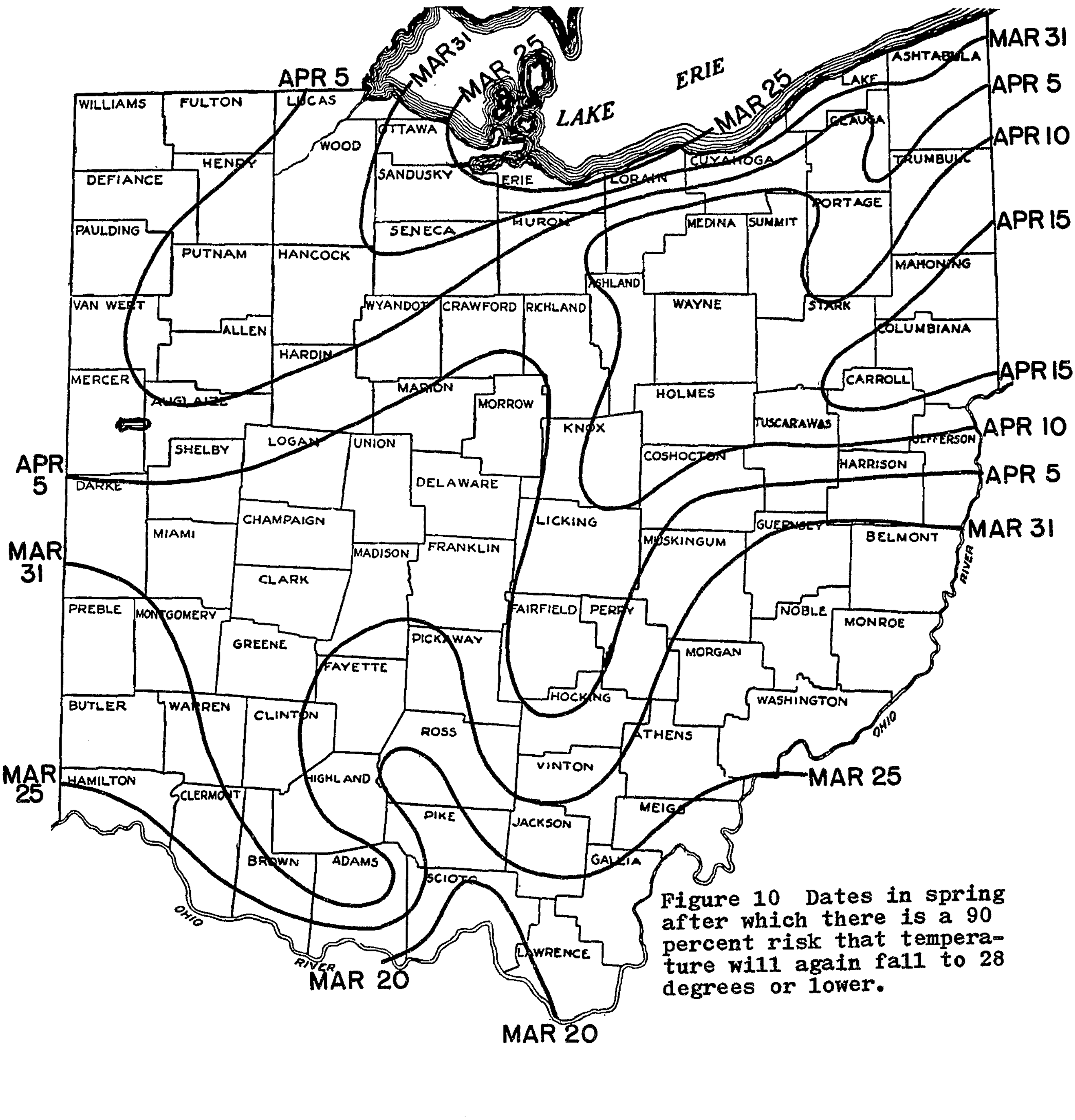

Figure 10 Dates in spring after which there is a 90 percent risk that temperature will again fall to 28 degrees or lower.

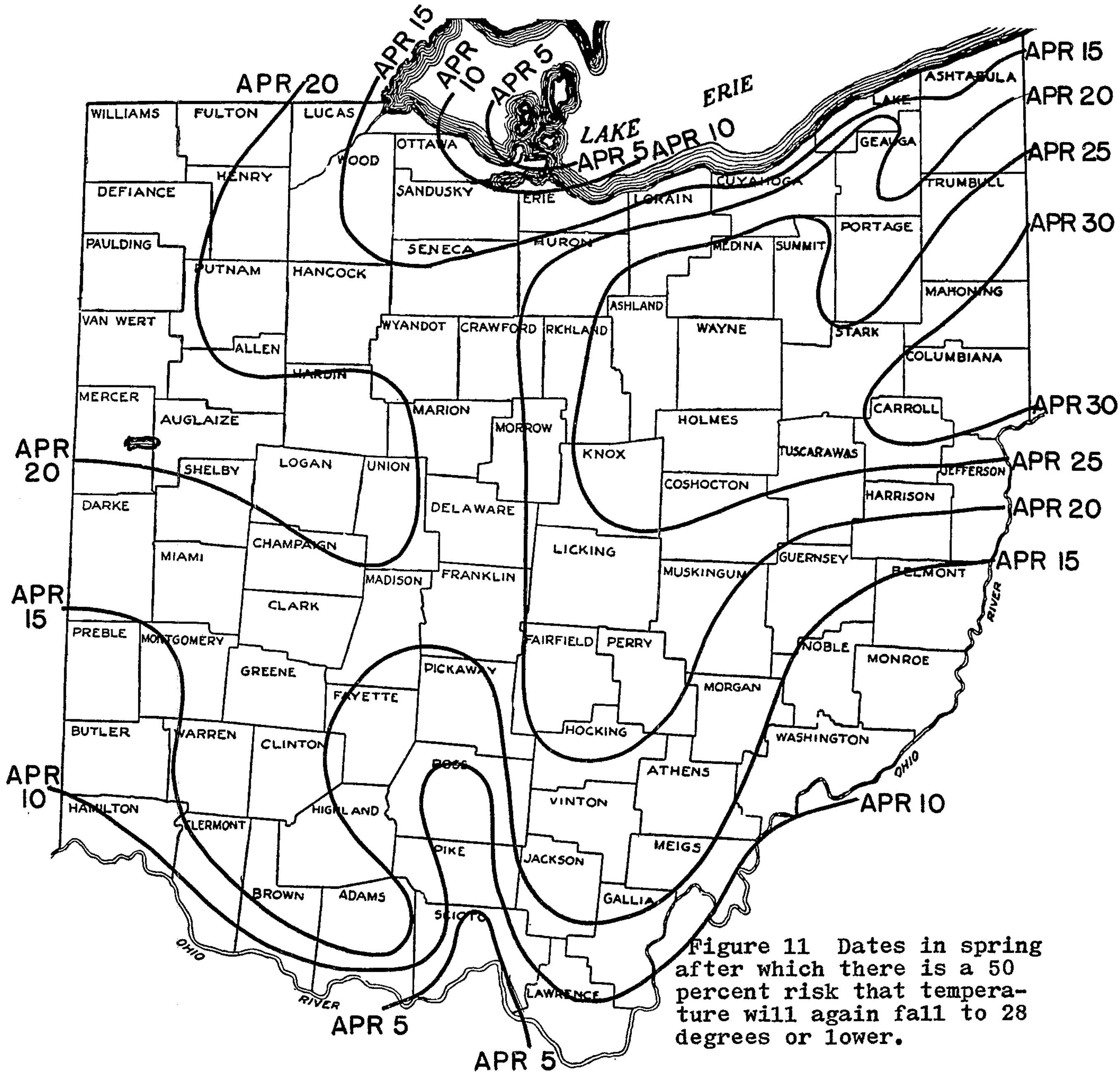

Figure 11 Dates in spring after which there is a 50 percent risk that temperature will again fall to 28 degrees or lower.

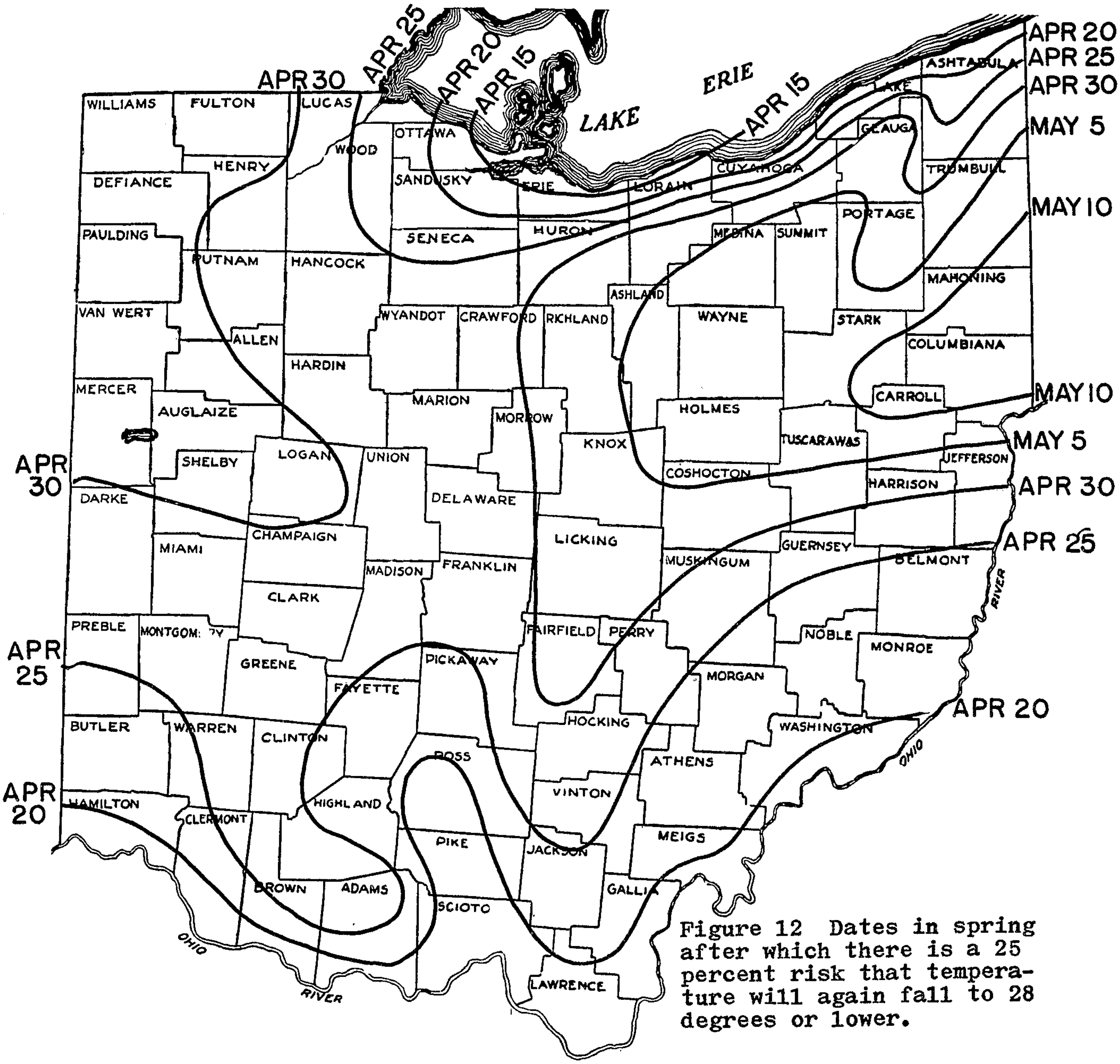

Figure 12 Dates in spring after which there is a 25 percent risk that temperature will again fall to 28 degrees or lower.

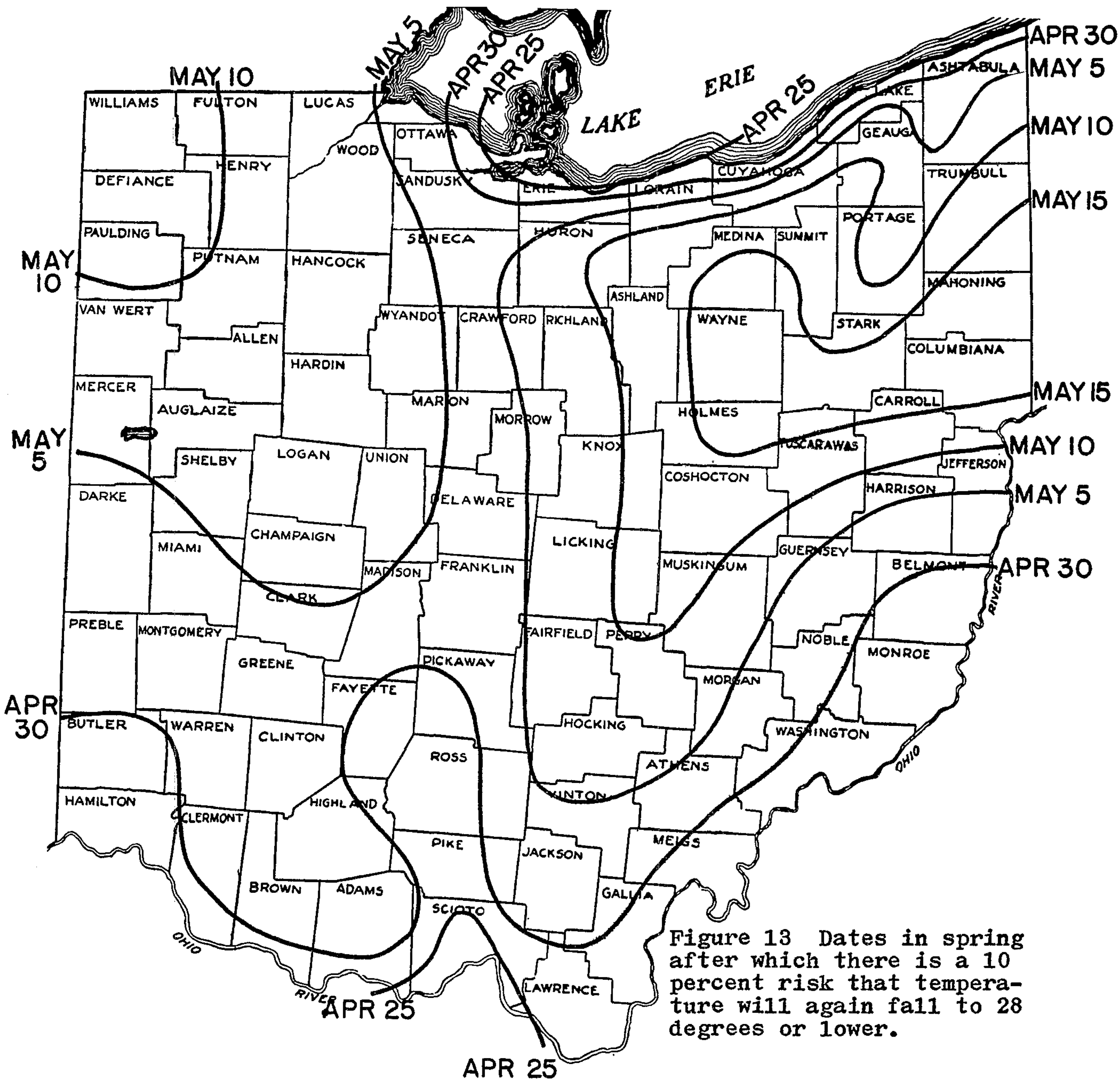

Figure 13 Dates in spring after which there is a 10 percent risk that temperature will again fall to 28 degrees or lower.

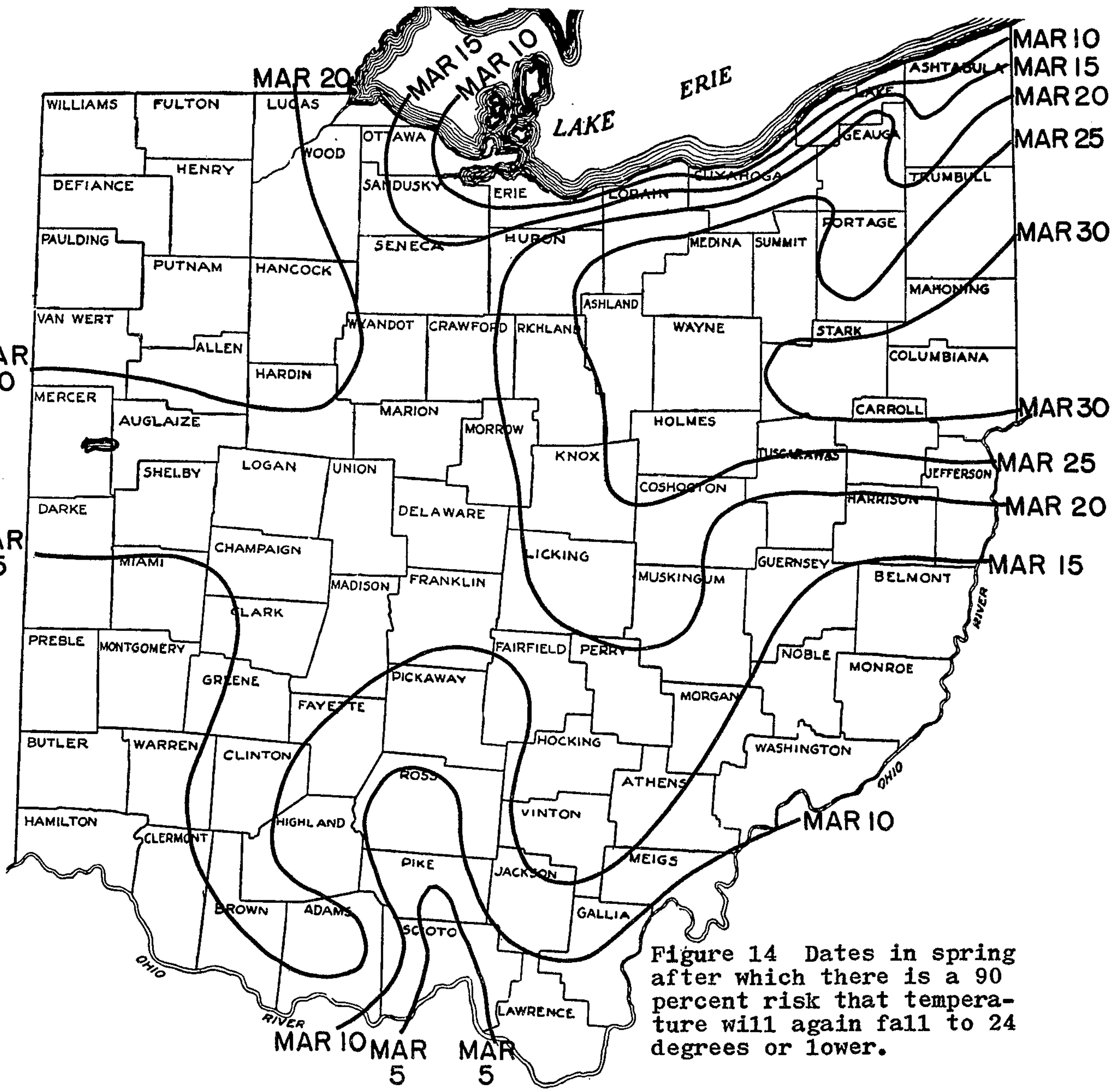

Figure 14 Dates in spring after which there is a 90 percent risk that temperature will again fall to 24 degrees or lower.

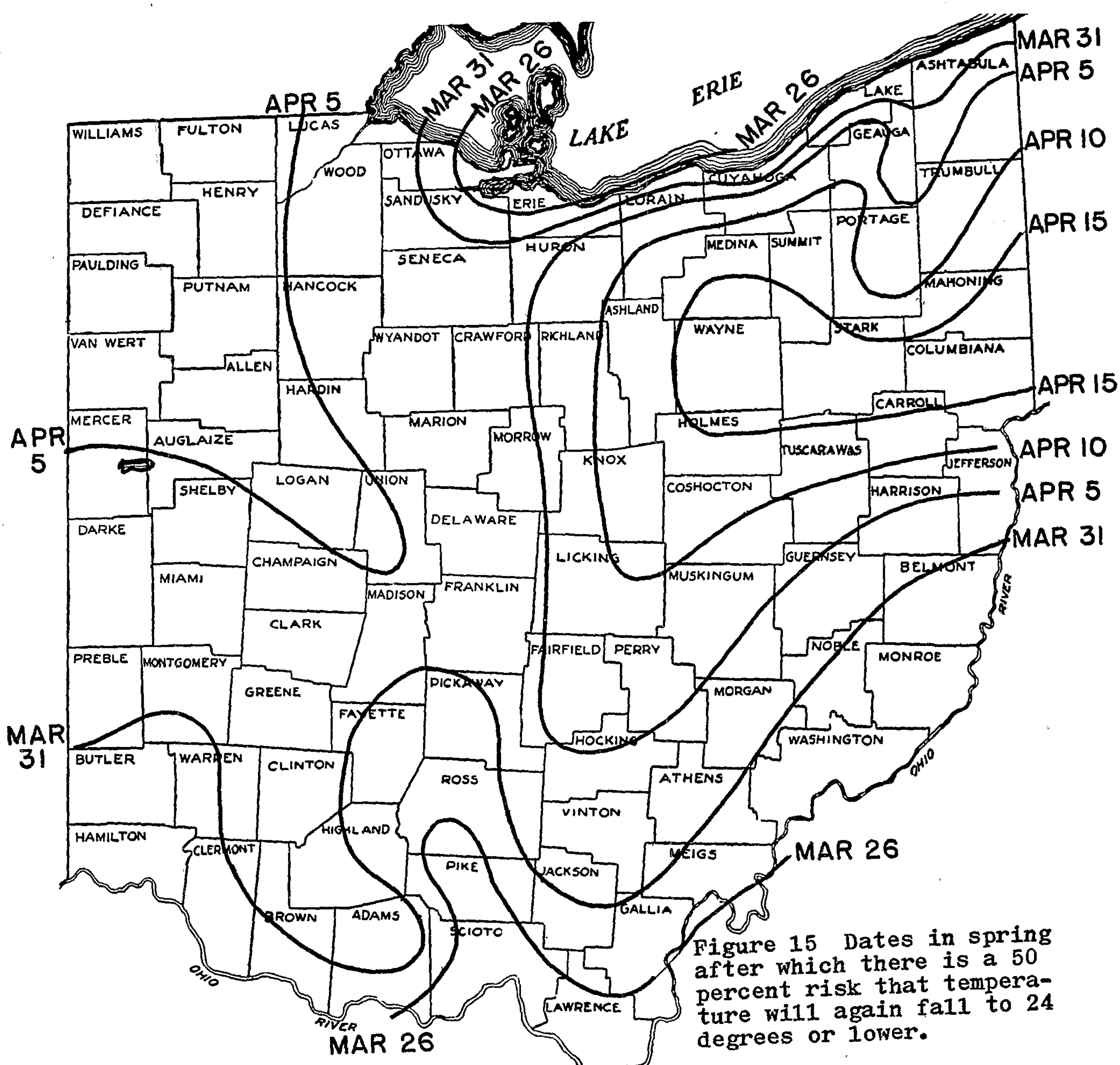

Figure 15 Dates in spring after which there is a 50 percent risk that temperature will again fall to 24 degrees or lower.

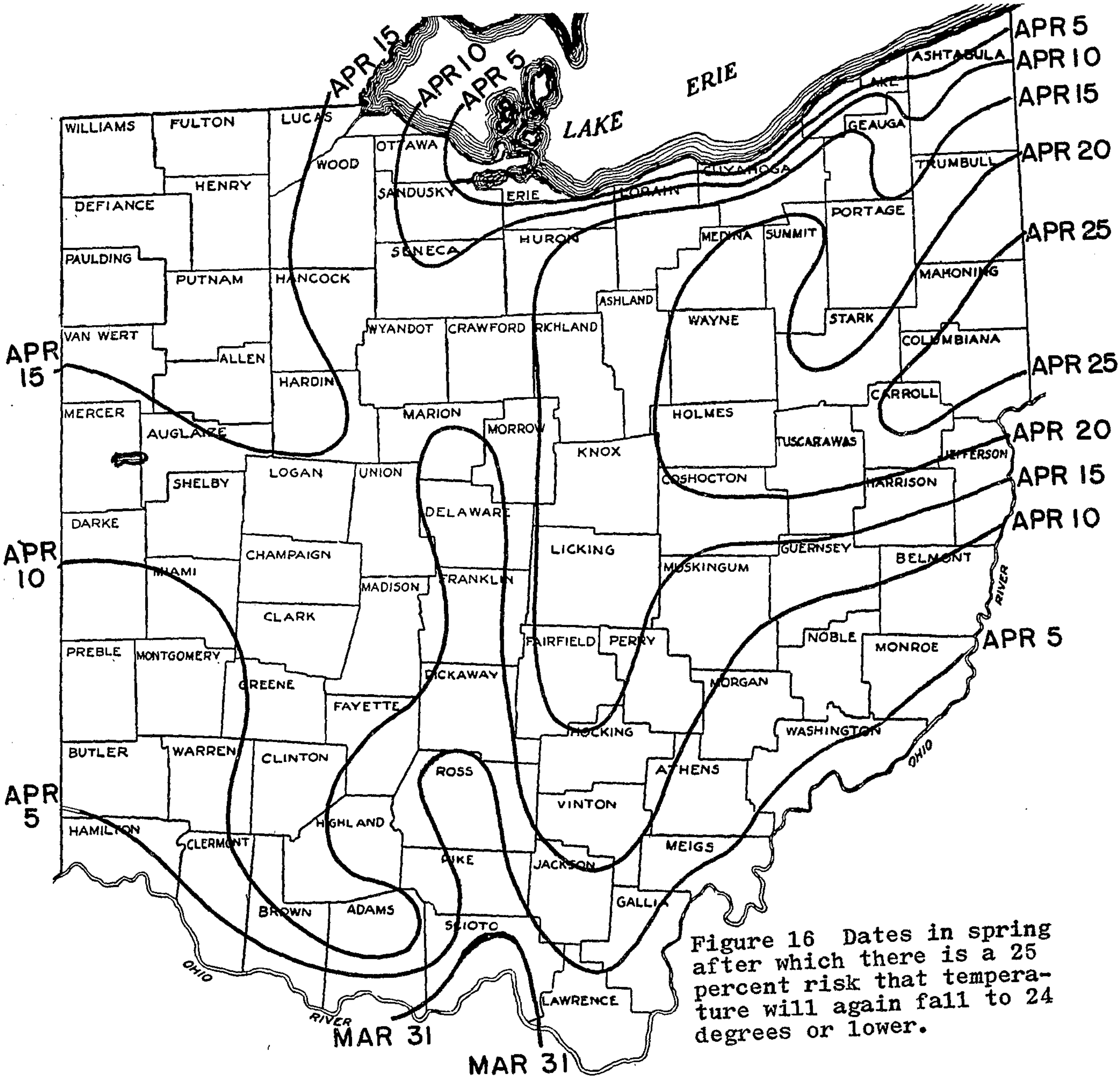

Figure 16 Dates in spring after which there is a 25 percent risk that temperature will again fall to 24 degrees or lower.

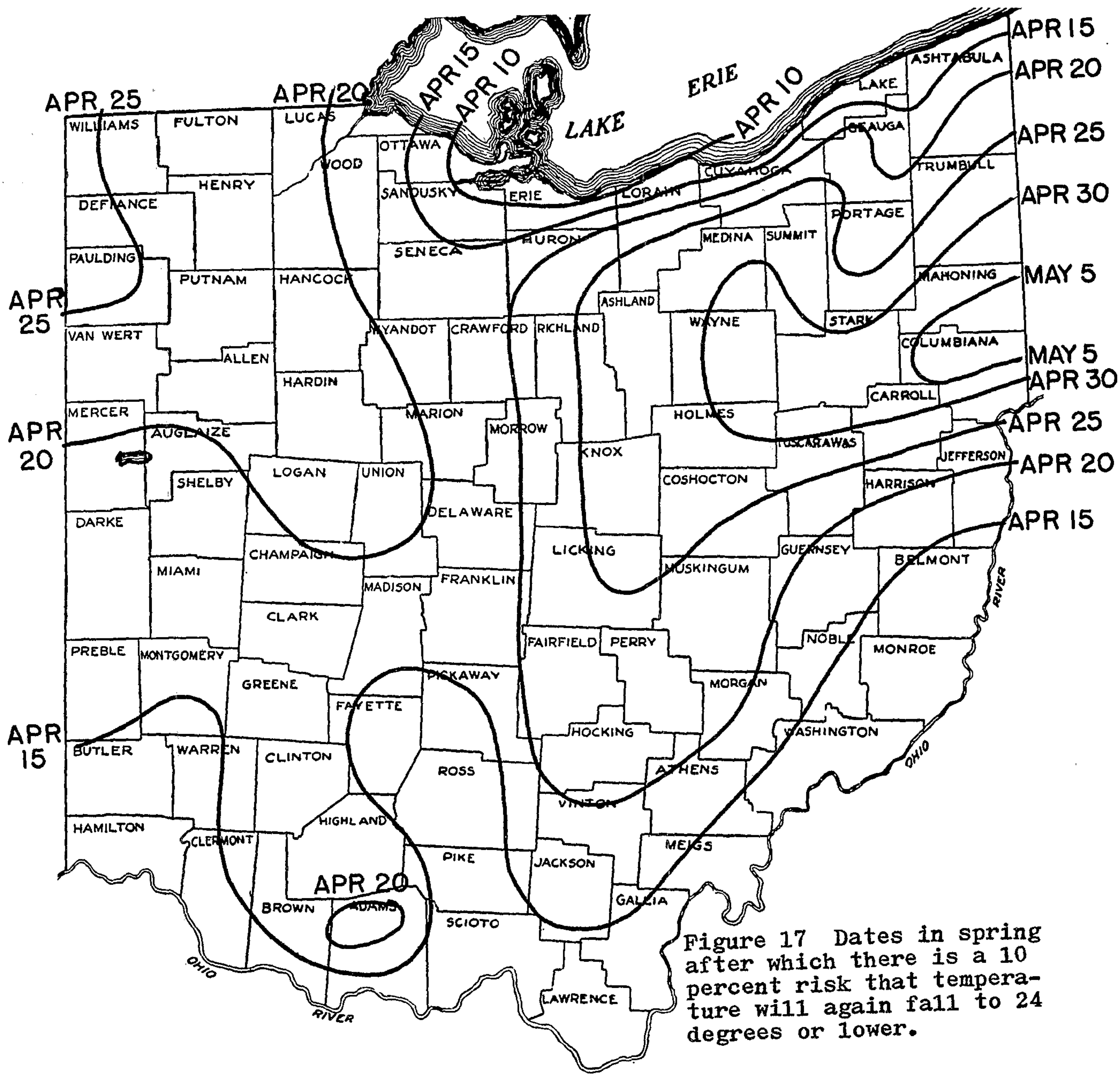

Figure 17 Dates in spring after which there is a 10 percent risk that temperature will again fall to 24 degrees or lower.

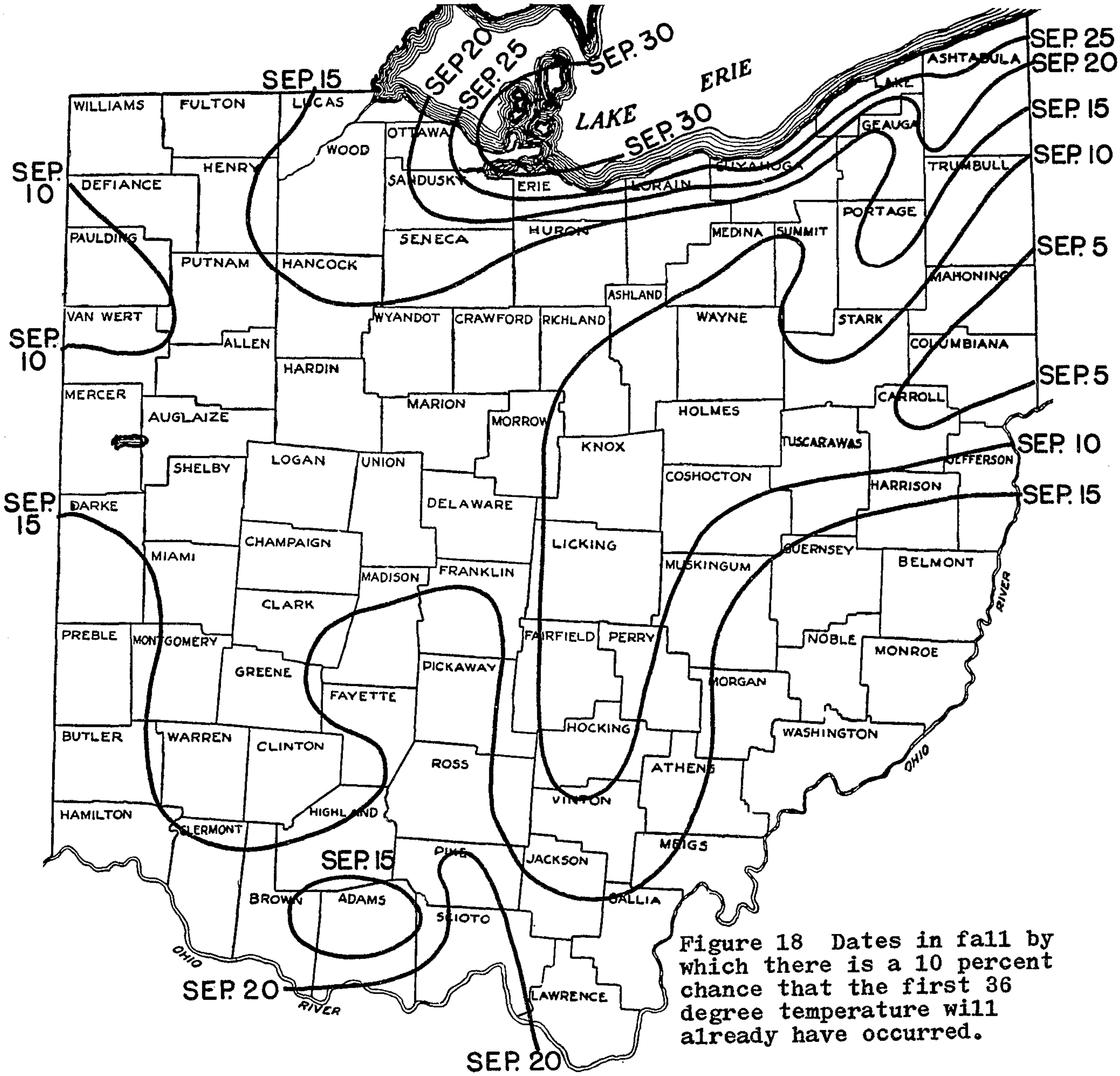

Figure 18 Dates in fall by which there is a 10 percent chance that the first 36 degree temperature will already have occurred.

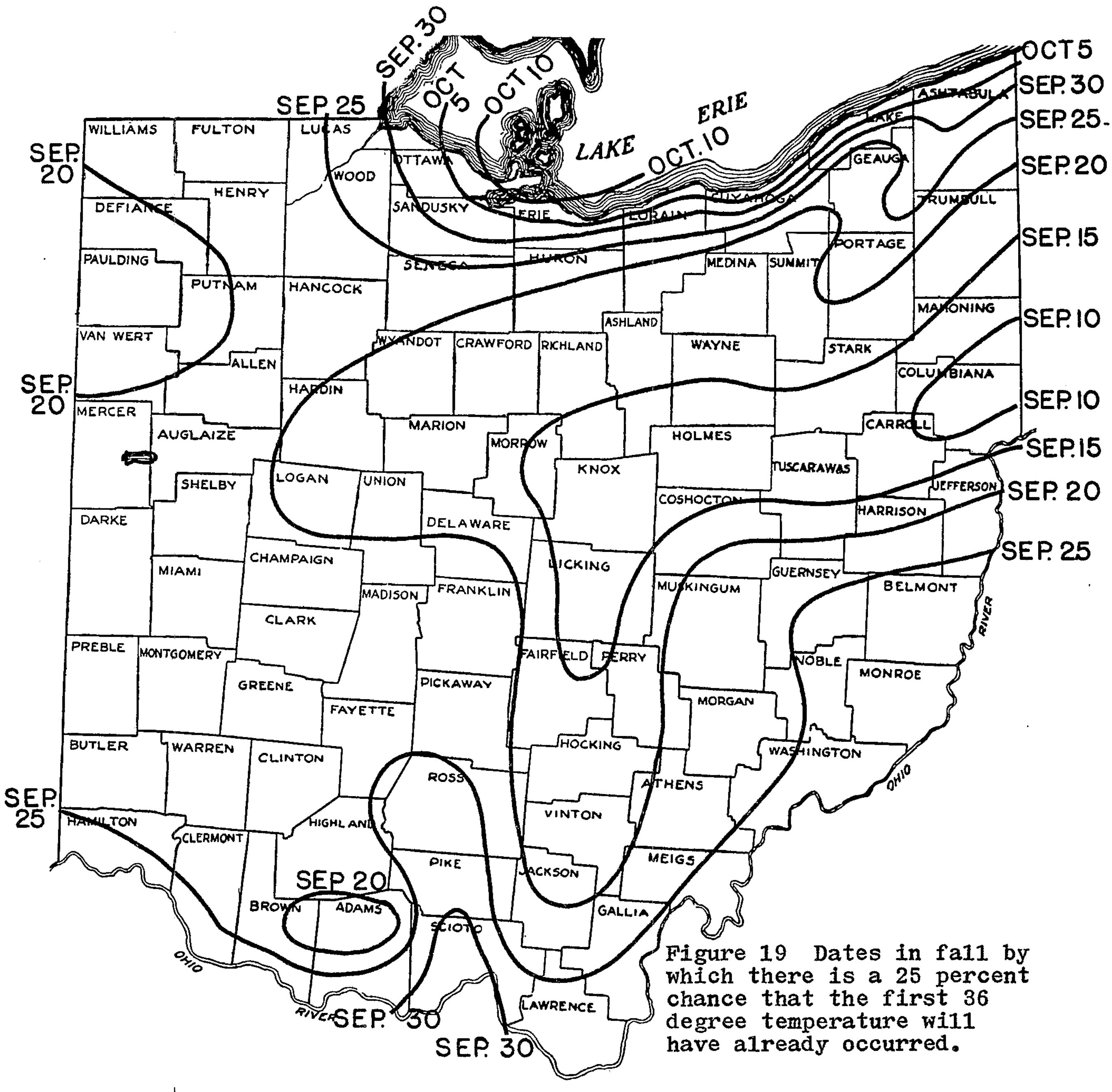

Figure 19 Dates in fall by which there is a 25 percent chance that the first 36 degree temperature will have already occurred.

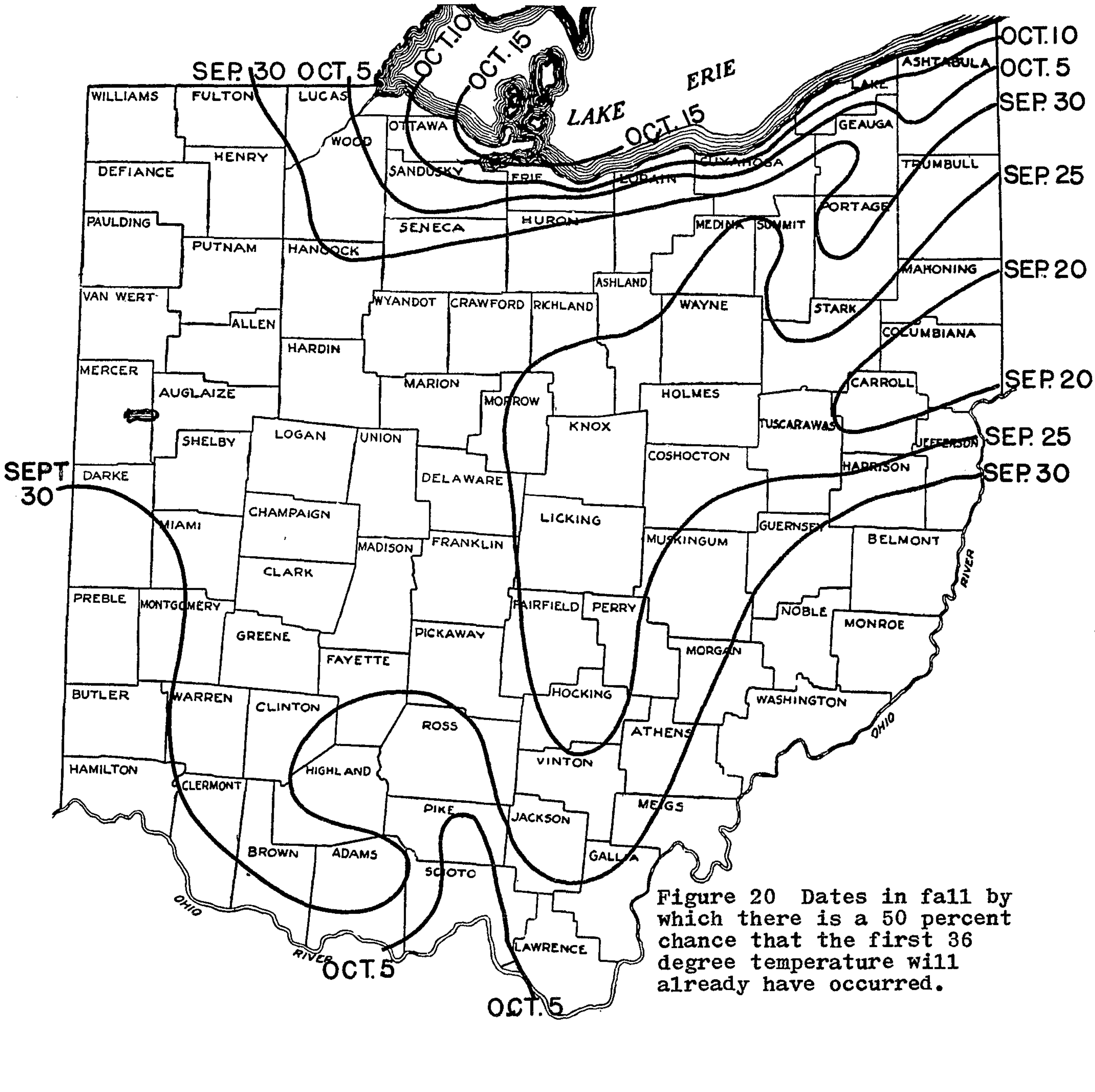

Figure 20 Dates in fall by which there is a 50 percent chance that the first 36 degree temperature will already have occurred.

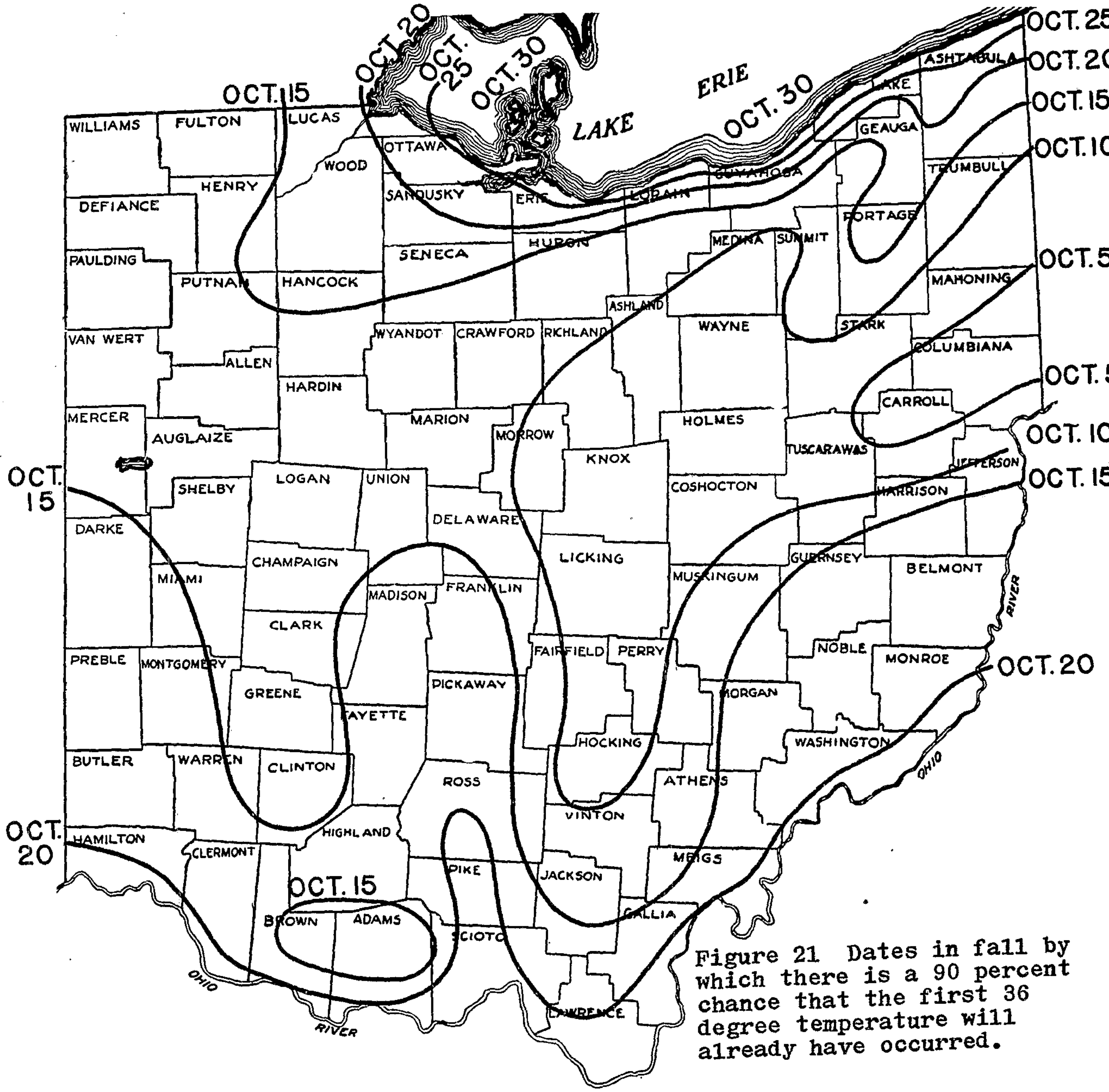

Figure 21 Dates in fall by which there is a 90 percent chance that the first 36 degree temperature will already have occurred.

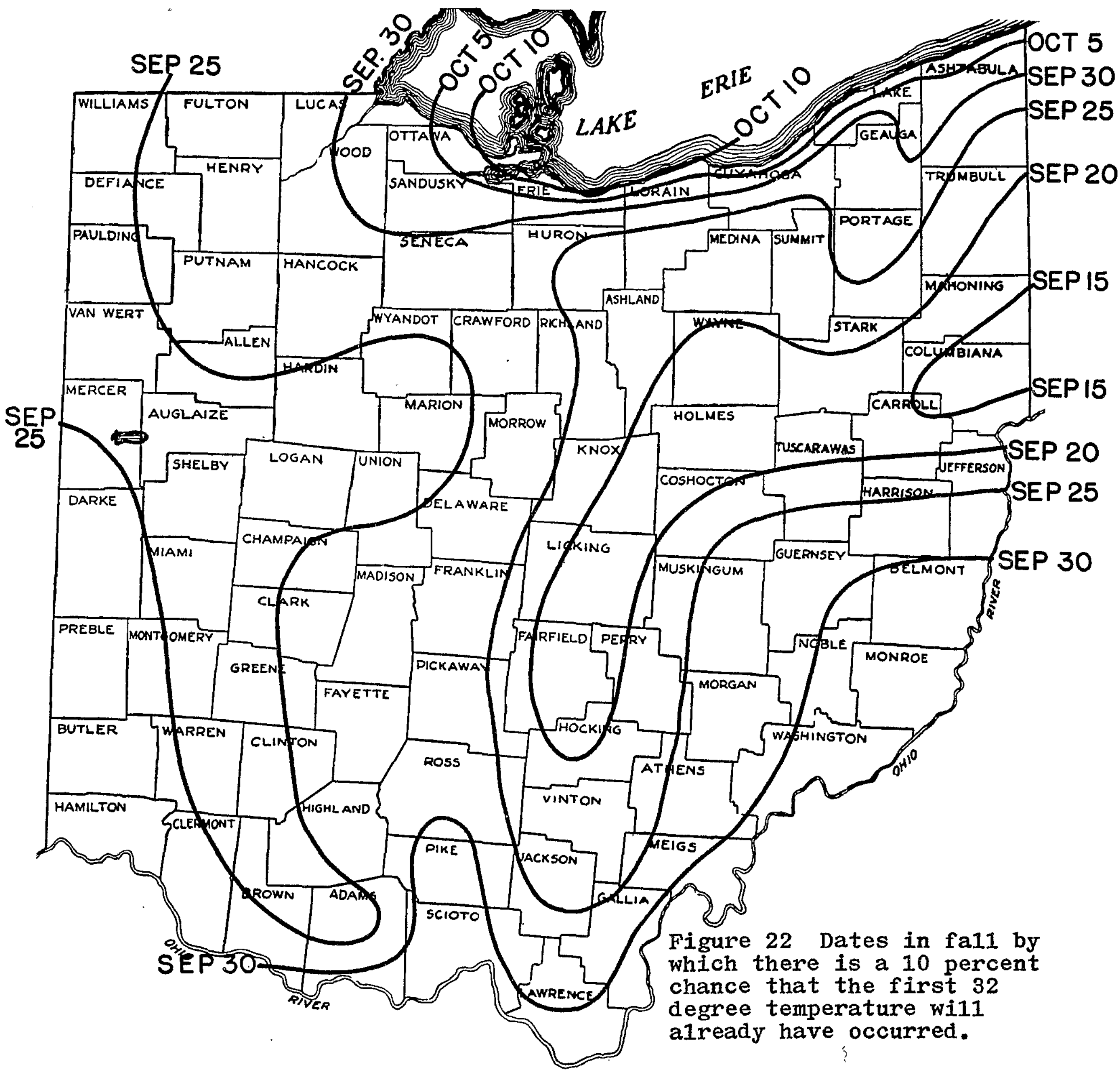

Figure 22 Dates in fall by which there is a 10 percent chance that the first 32 degree temperature will already have occurred.

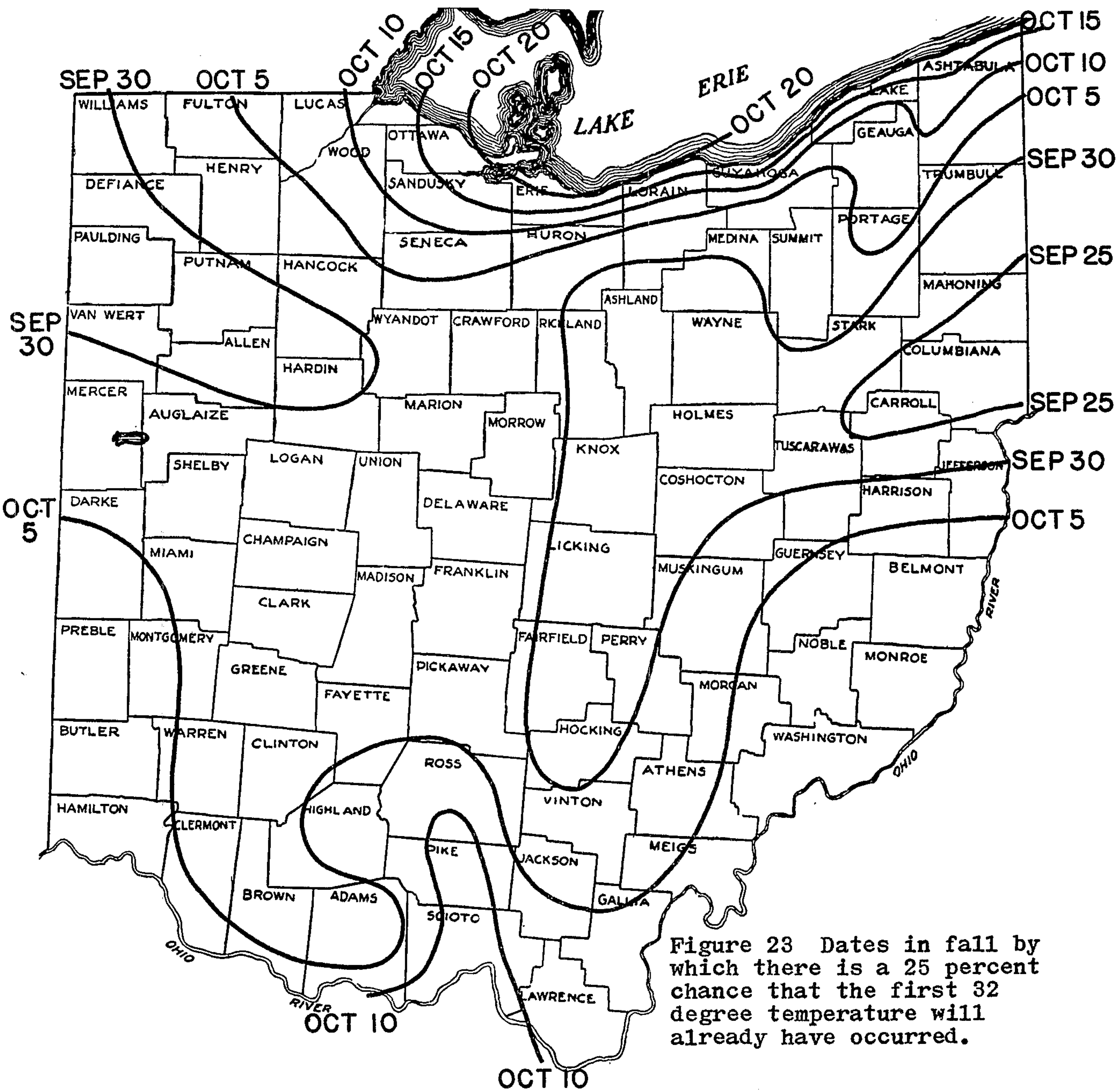

Figure 23 Dates in fall by which there is a 25 percent chance that the first 32 degree temperature will already have occurred.

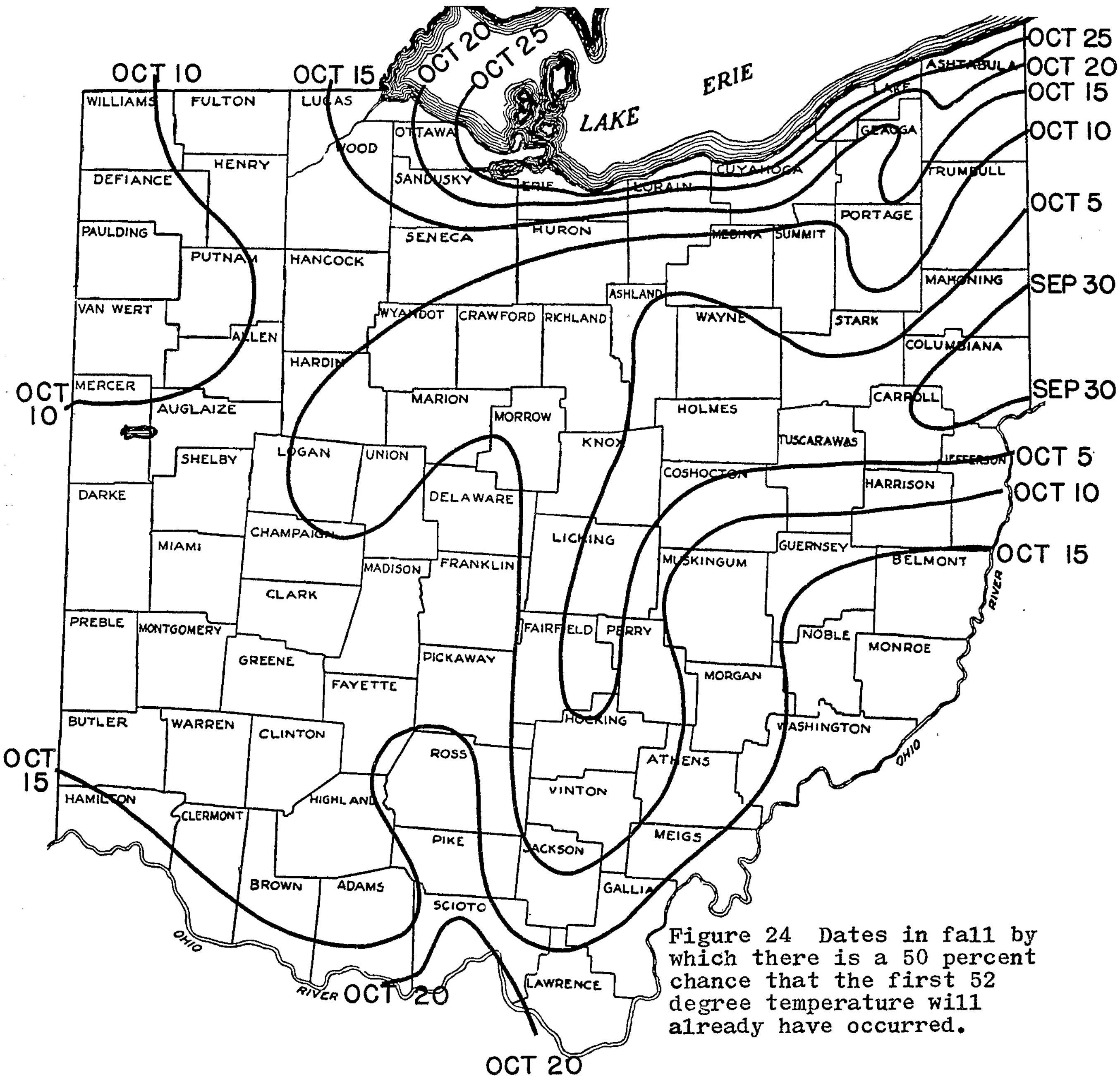

Figure 24 Dates in fall by which there is a 50 percent chance that the first 52 degree temperature will already have occurred.

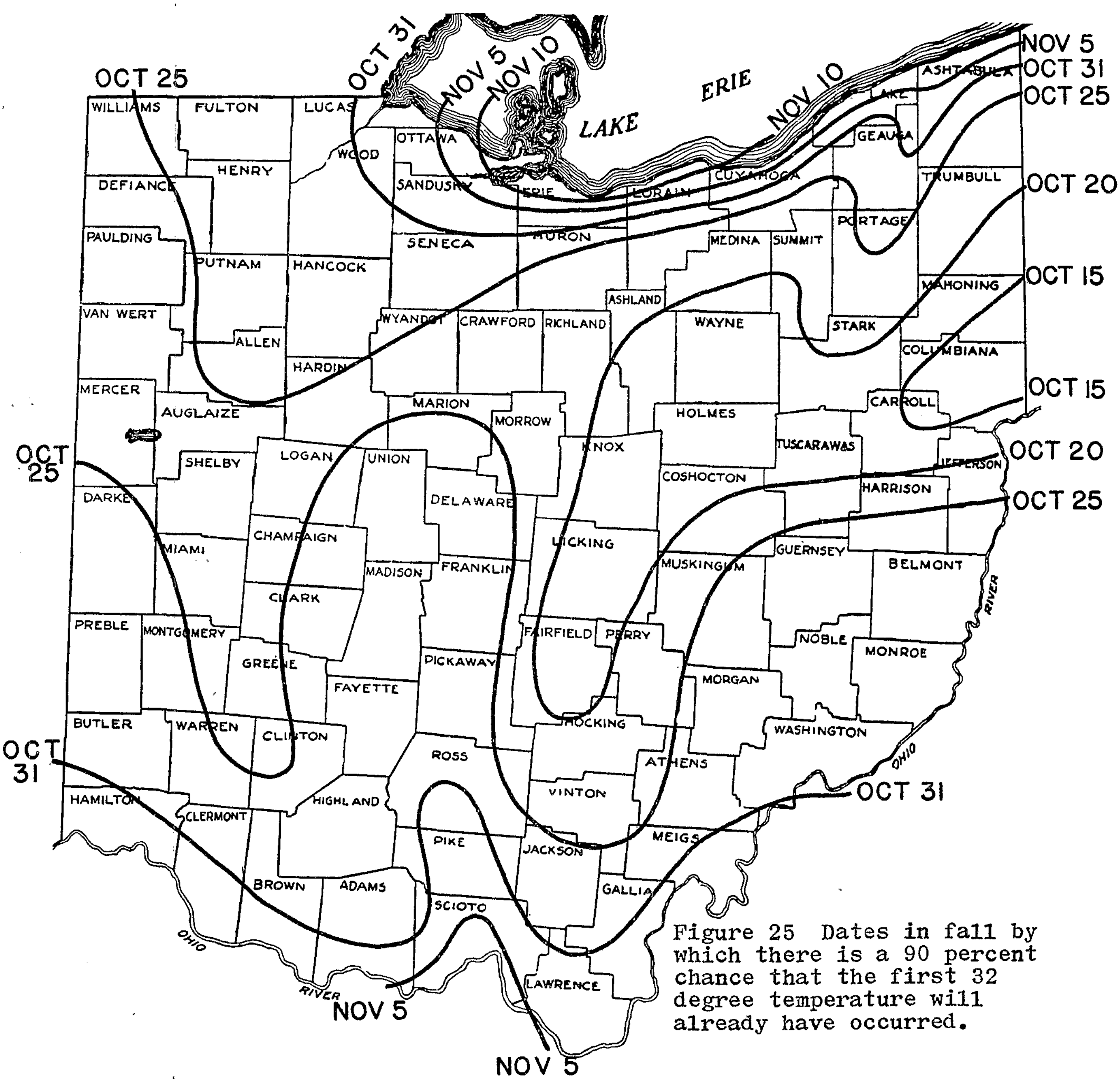

Figure 25 Dates in fall by which there is a 90 percent chance that the first 32 degree temperature will already have occurred.

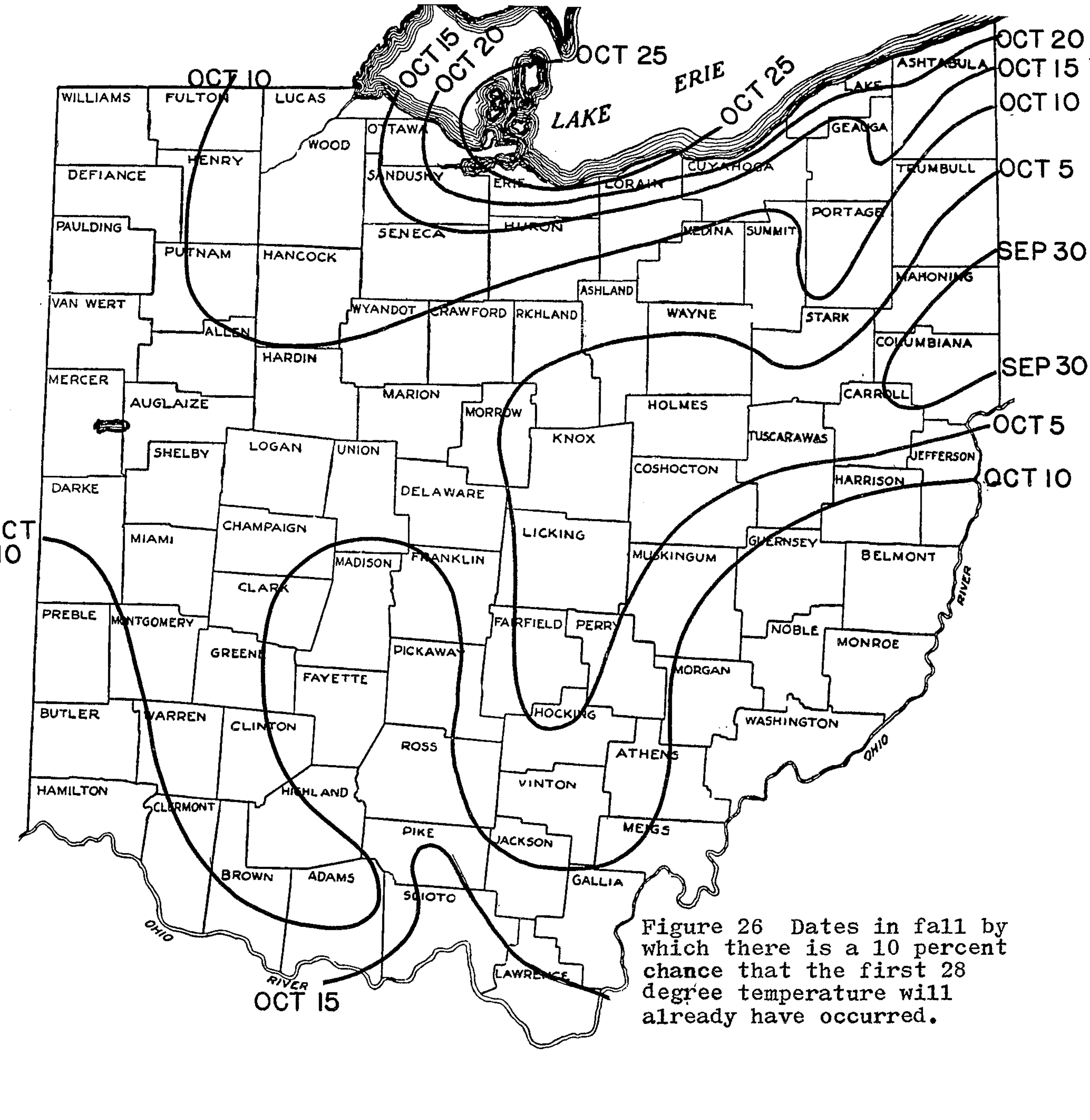

Figure 26 Dates in fall by which there is a 10 percent chance that the first 28 degree temperature will already have occurred.

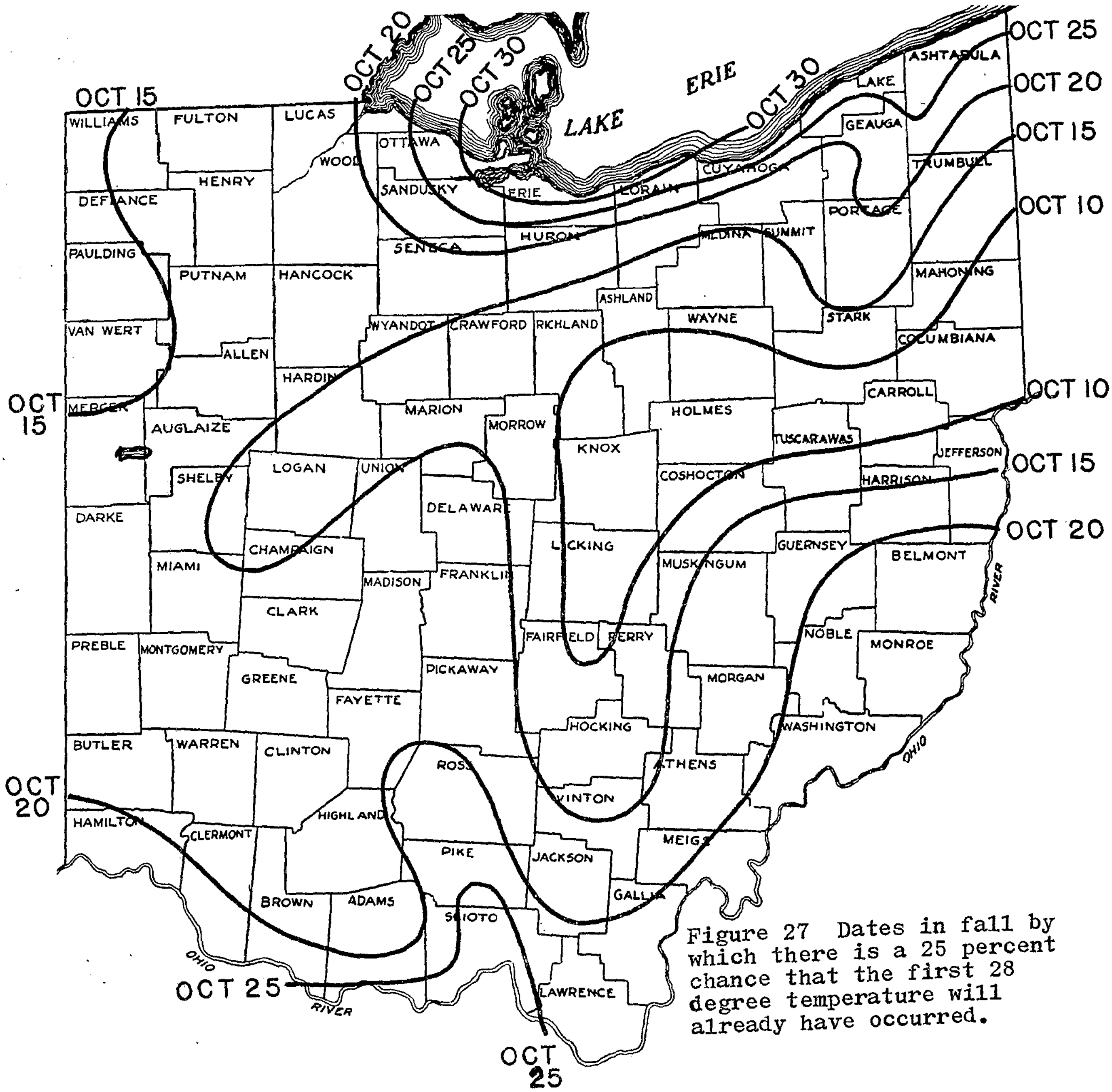

Figure 27 Dates in fall by which there is a 25 percent chance that the first 28 degree temperature will already have occurred.

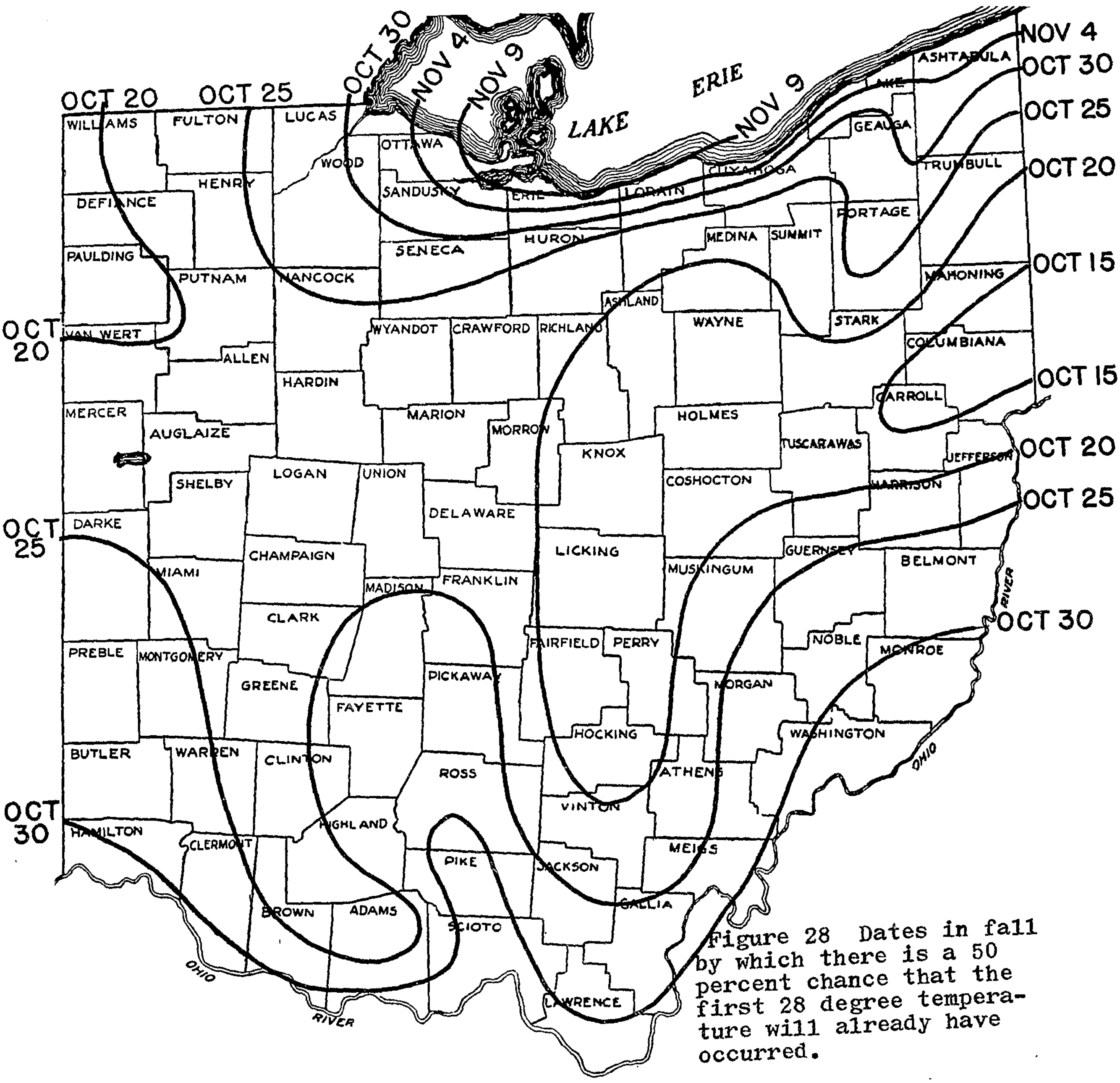

Figure 28 Dates in fall by which there is a 50 percent chance that the first 28 degree temperature will already have occurred.

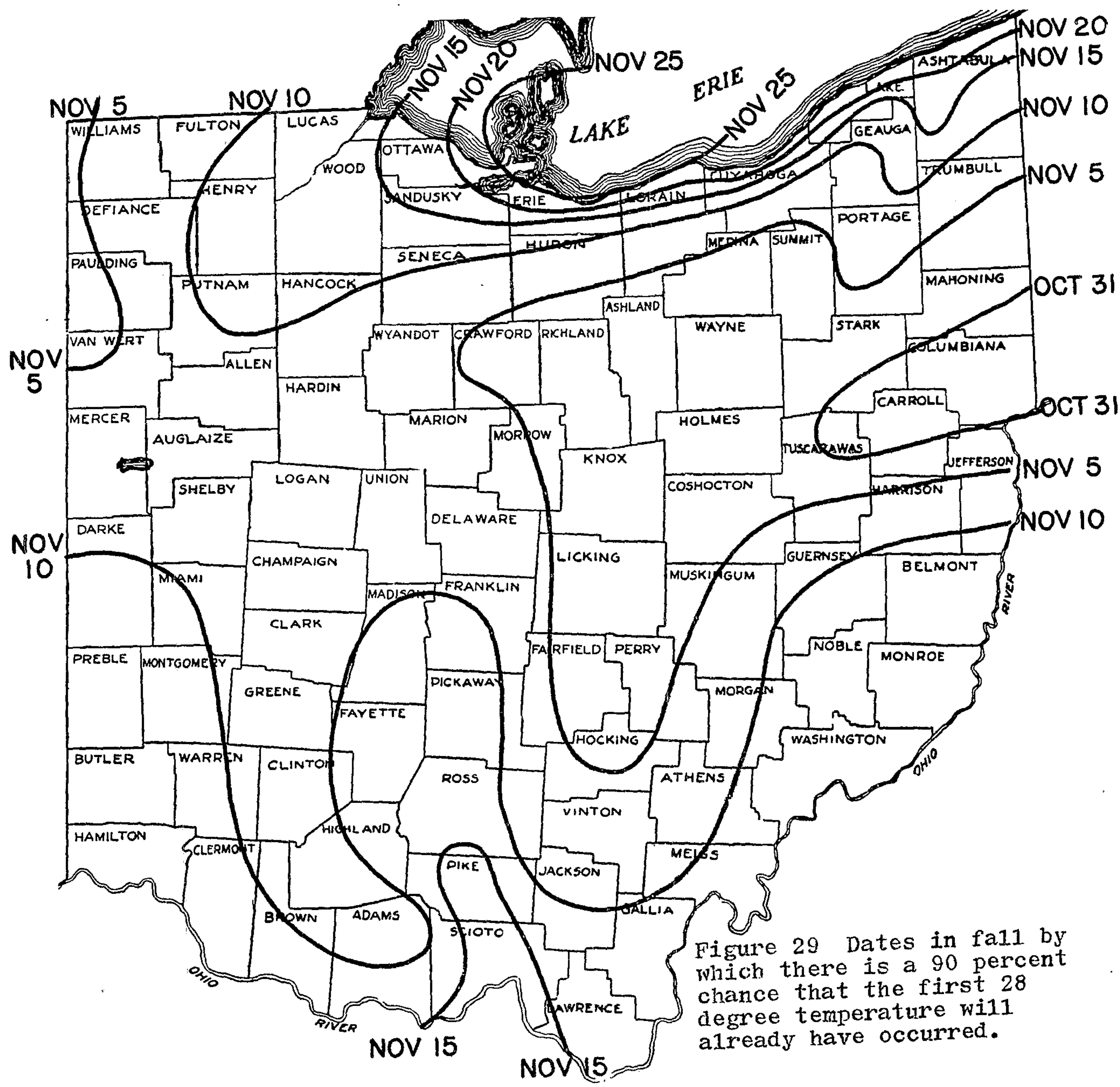

Figure 29 Dates in fall by which there is a 90 percent chance that the first 28 degree temperature will already have occurred.

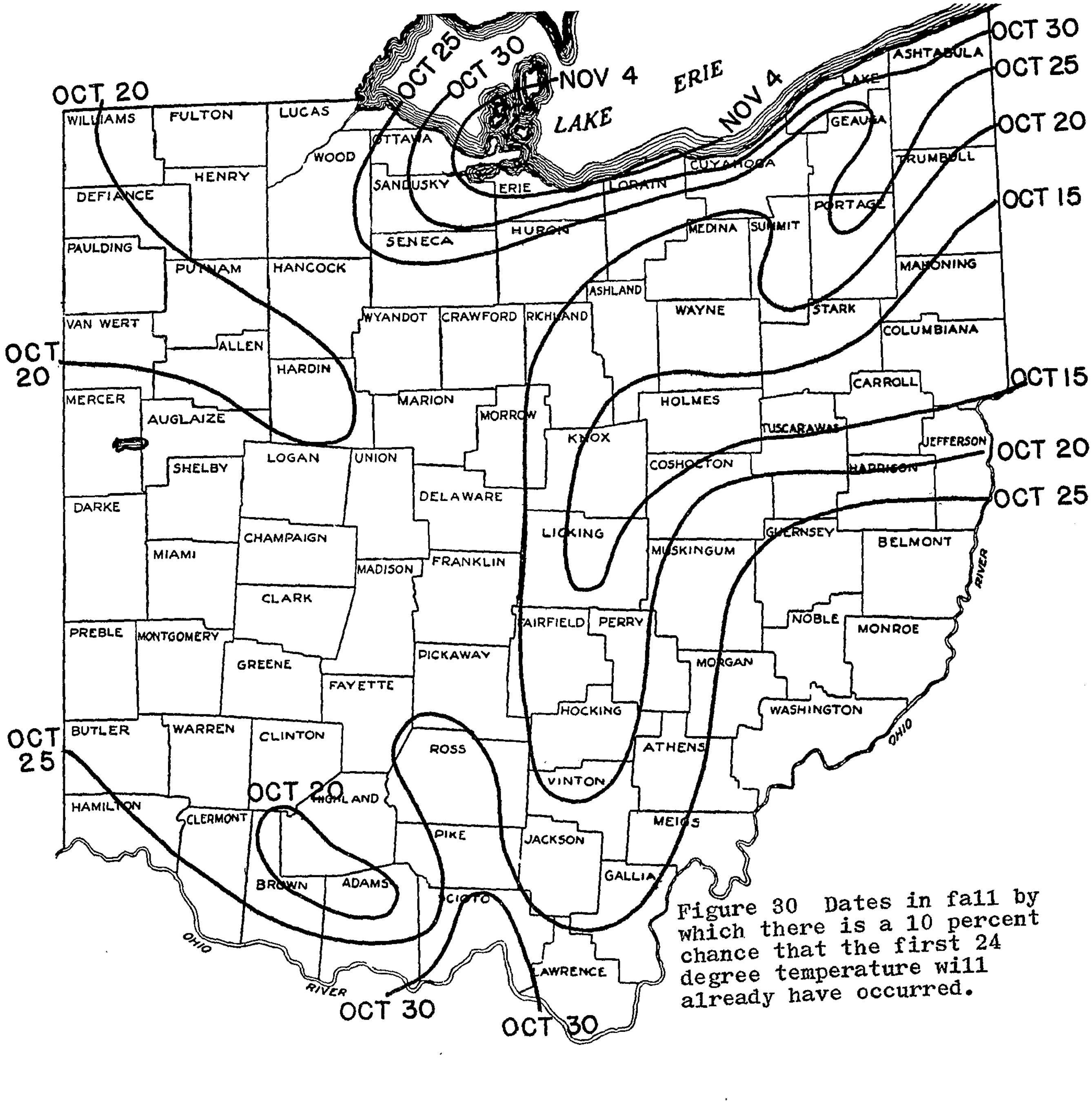

Figure 30 Dates in fall by which there is a 10 percent chance that the first 24 degree temperature will already have occurred.

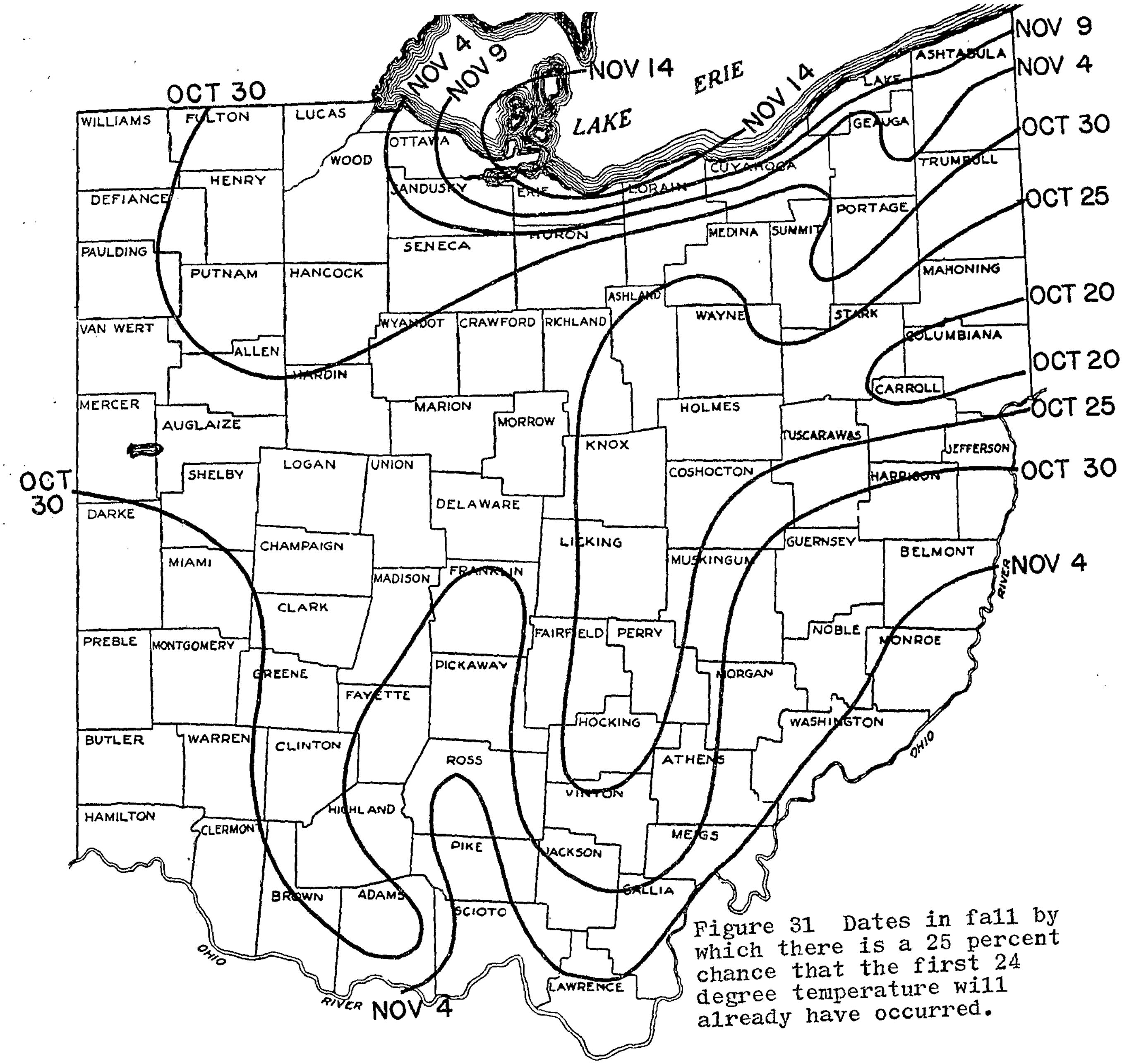

Figure 31 Dates in fall by which there is a 25 percent chance that the first 24 degree temperature will already have occurred.

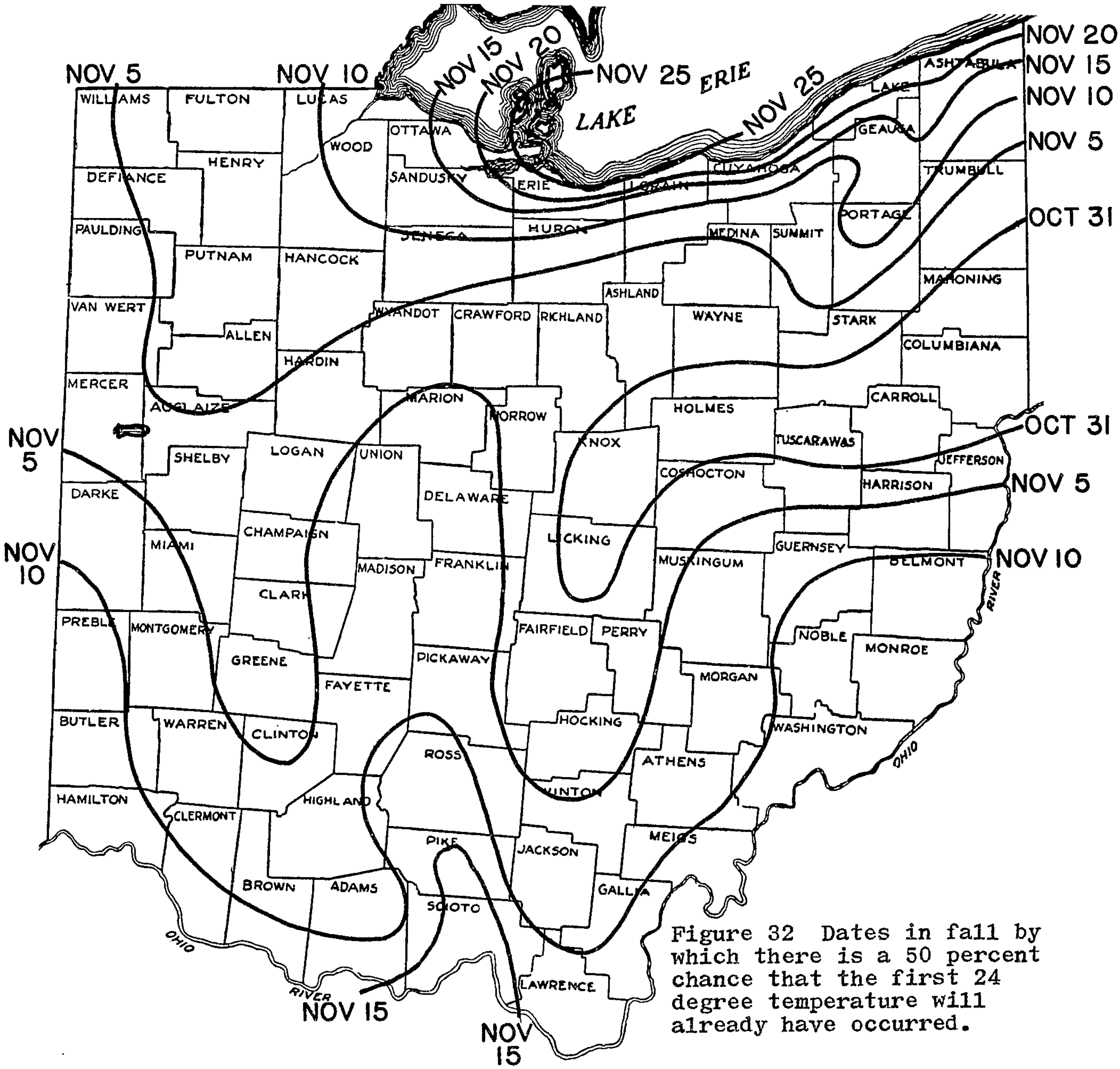

Figure 32 Dates in fall by which there is a 50 percent chance that the first 24 degree temperature will already have occurred.

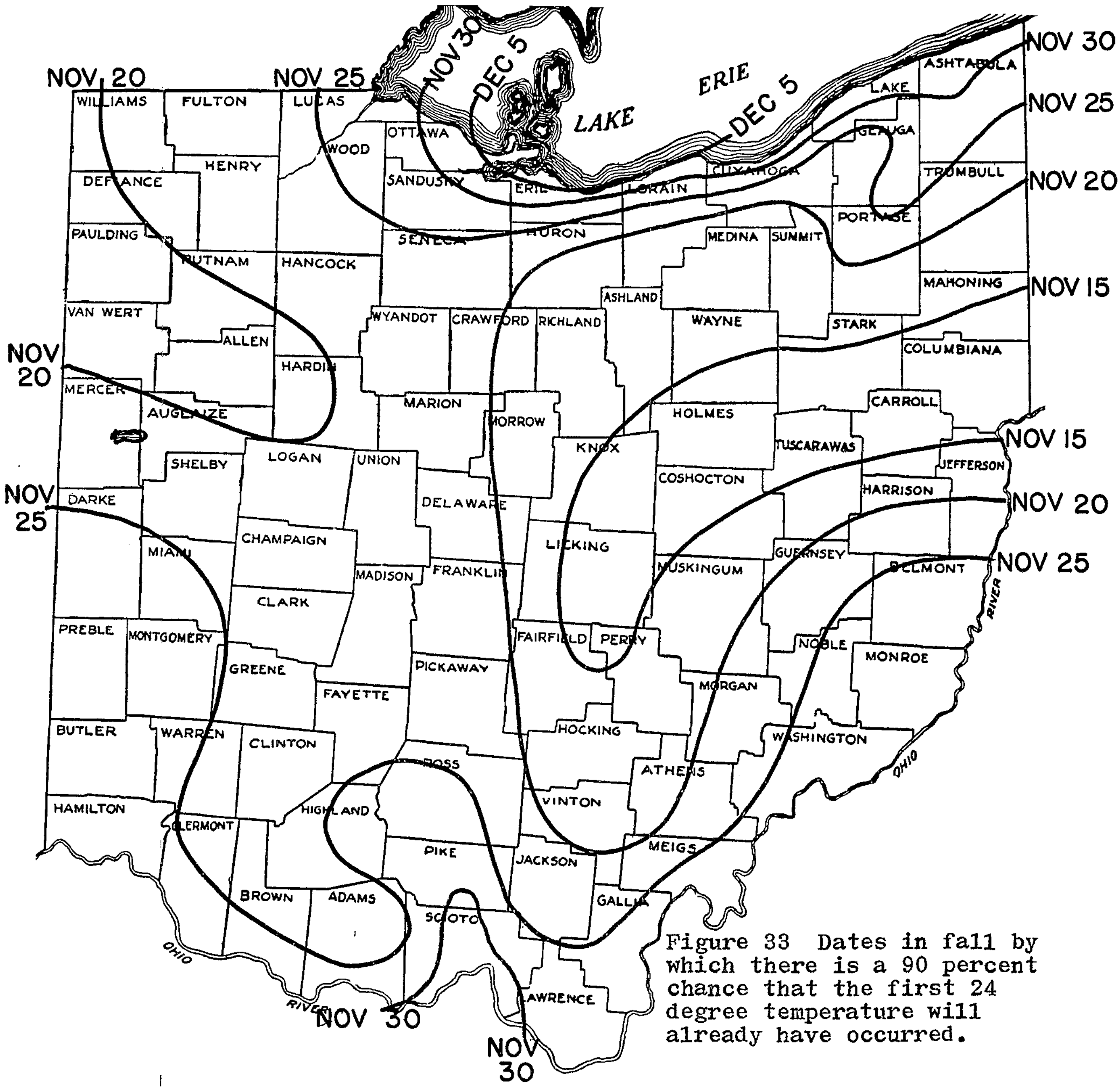

Figure 33 Dates in fall by which there is a 90 percent chance that the first 24 degree temperature will already have occurred.

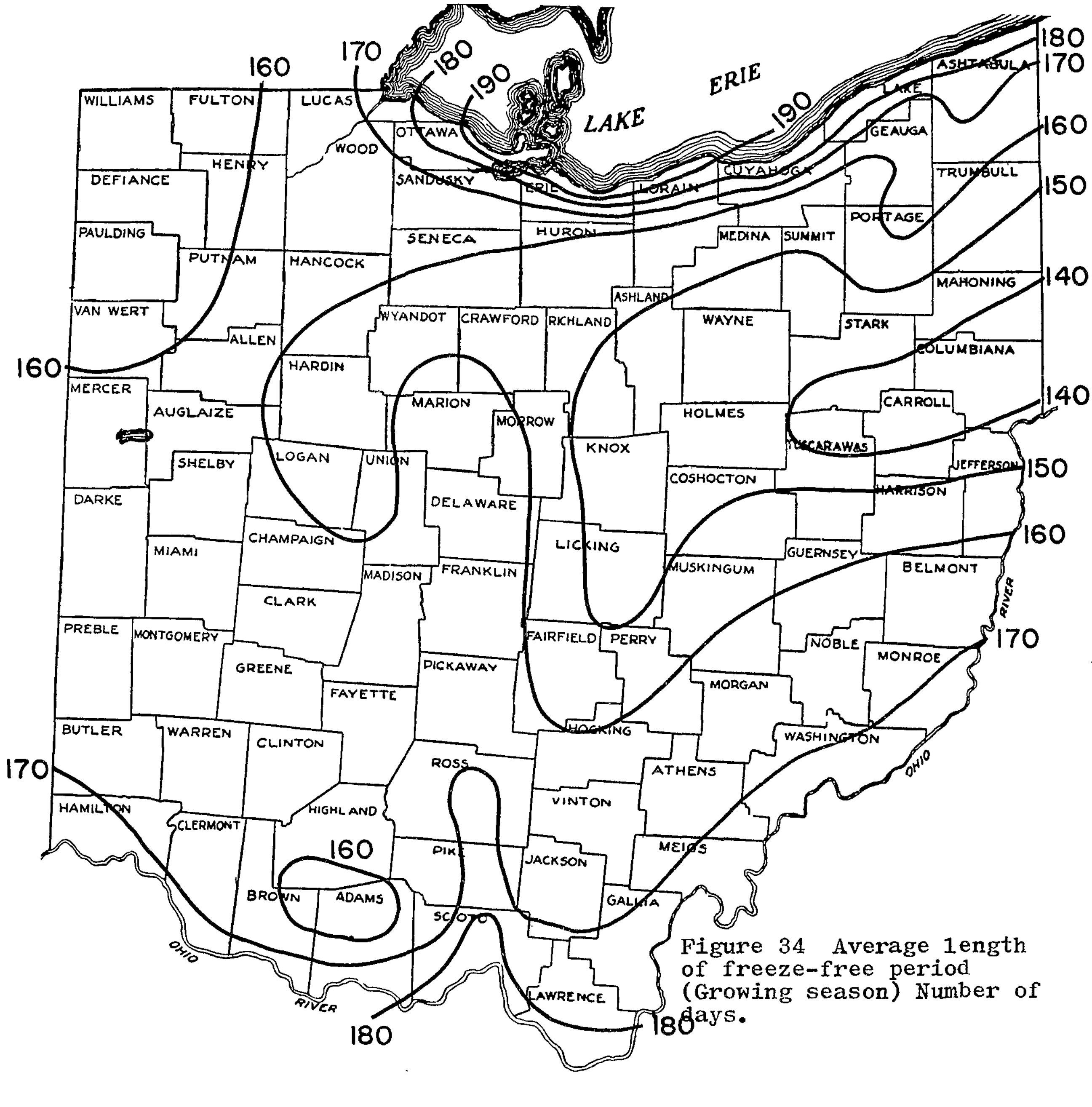

Figure 34 Average length of freeze-free period (Growing season) Number of days.